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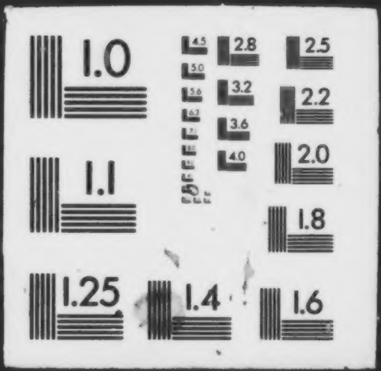
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Phase II Report

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The Phase II report of the National Pesticide Survey Studies how detections and concentrations of nitrate and pesticides in drinking water wells are affected by the sensitivity of groundwater to contamination, use of fertilizers and pesticides, precipitation, irrigation, the chemical characteristics of pesticides, and the age, depth, construction, and location of community water supply wells and rural domestic water supply wells.

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Executive Summary

The U.S. Environmental Protection Agency (EPA) has completed the Phase II Report for its National Survey of Pesticides in Drinking Water Wells (NPS). Between 1988 and 1990, EPA sampled 1349 community water system (CWS) wells and rural domestic drinking water wells for the presence of 101 pesticides, 25 pesticide degradates, and nitrate (127 analytes). The Phase II Report describes the outcome of an extensive analysis of factors potentially affecting pesticide and nitrate occurrence in drinking water wells.

EPA designed the Survey with two principal objectives corresponding to its two phases. In Phase I, completed in November 1990, EPA developed national estimates of the frequency and concentration of pesticides and nitrate present in drinking water wells in the United States. In Phase II, EPA investigated the NPS data alone and in combination with pertinent data from non-NPS sources. The Phase II analyses sought to improve EPA's understanding of how the presence of pesticides and nitrate (measured as N) in drinking water wells is associated with patterns of pesticide use, the sensitivity of areas surrounding drinking water wells to ground-water contamination, transport of chemicals to well water, and other factors, including pesticide chemistry and the physical condition of drinking water wells.

Discussion of Findings

The NPS, as a whole, represents the only national data currently available to EPA on the extent and nature of the presence of pesticides and nitrate in drinking water wells. The NPS Phase II analysis investigated possible correlations or associations between detections of pesticides or nitrate in drinking water wells and a number of factors that might be related to their presence in those wells.

Statistical Methods

The Phase II analysis followed standard statistical procedures to evaluate the data gathered by the Survey. EPA tested hypotheses about the relation between individual variables and pesticide and nitrate detections and the degree of association between them. EPA used a criterion of significance that ensures that there was less than a 5 percent probability that any single test result occurred by chance alone. The Phase II analyses include tests of association which use chi square analysis, linear and logistic univariate regression, and multiple regression to better understand the association of pesticide and nitrate detections in drinking water wells with ground-water sensitivity, pesticide and nitrate use, transport mechanisms, pesticide chemistry, and well condition, as each of them was defined for the NPS analysis.

The results obtained by the Phase II analysis represent associations between detections of pesticides or nitrate in wells and other factors that may indicate the presence of chemicals in water from drinking water wells. The findings reported in the Phase II Report have passed appropriate statistical tests for significance and have been examined for consistency with current theories of well-water contamination as well as the results of other selected similar surveys. Because the NPS was designed first and foremost to satisfy the objective of generating national estimates of pesticide and nitrate contamination of drinking water wells, the statistical analysis of Phase II was constrained in a number of ways. Most important, the set of hypotheses that could be examined accurately was restricted by the number of observed detections. The number of detections were limited by two factors: sample size and reporting limits. The number of samples taken was limited to the number sufficient to produce the national estimates presented in the Phase I Report. Multi-residue chemical analytic methods using stringent minimum reporting limits (MRLs) and confirmation of detections ensured that false positive results were avoided when detections in drinking water wells were reported. The statistical techniques used in Phase II require larger numbers of detections to perform effectively than the techniques for estimating population proportions and their standard errors used in Phase I. The effective number of detections for nitrate was approximately 220 in CWS wells and 232 in rural domestic wells; the effective detection size for the "any pesticide" variable, the next largest chemical group included in the analysis, was approximately 44 for CWS wells and 17 for rural domestic wells. In certain cases, the number of detections of DCPA acid metabolites in wells also was sufficient to allow statistical analysis to be carried out. The other detected analytes were detected in wells too few times to be included separately in the analyses.

Data Sources

The data used in the Phase II analysis came from a broad range of sources. Generally either the reported *detections* of pesticides or nitrate in wells or the *concentrations* of nitrate in wells were evaluated for associations with factors that could serve as indicators of contamination in drinking water wells. Only detections above the NPS MRLs reported by the primary laboratories were used in the analysis. In a few cases, when concentrations could not be reliably measured above the MRL, the corresponding detections were not included in the analysis to ensure consistency and accuracy in results. Detections reported only by NPS referee laboratories are not included because those laboratories provided quality assurance review rather than comprehensive analysis of all samples.

The other variables included in the analysis came both from data generated by the NPS and data obtained from sources outside the Survey. Data sources include the following:

- **Data collected from NPS questionnaires**. Data on pesticide use, spills, and disposal; agricultural activities; well age, depth, and construction; topography; and surface water near the well were developed from information collected on NPS questionnaires. (Copies of the NPS questionnaires and summaries of much of the data collected from the questionnaires can be found in the NPS Phase I Report.)

- **Data from NPS stratification**. EPA developed county-level and sub-county level DRASTIC measures of ground-water vulnerability, using a broad variety of geologic and hydrogeologic data often obtained from U.S. Geologic Service sources. EPA also developed measures of agricultural pesticide use intensity, using data on pesticide sales and cropping, and a sub-county measure of "cropped and vulnerable" used to identify sensitive sub-county areas. The pesticide sales data were from a proprietary data base generated by Doanes Marketing Research, Inc. with data from 1984.

- **Pesticide use data**. EPA developed county-level estimates of pesticide use in agricultural and non-agricultural applications from regional and state-level data assembled for EPA by Resources for the Future.

- **Fertilizer sales data**. EPA developed county-level estimates of fertilizer sales from materials collected under contract for EPA, including state-level data collected by the Tennessee Valley Authority.

- **Data from the U.S. Department of Agriculture's Census of Agriculture**. EPA obtained county-level data on agricultural activities in the United States from the 1987 Census of Agriculture from which measures of crop values, cropping activity, and livestock operations were extracted.

- **Rainfall and drought data**. EPA obtained data from the National Climate Data Service of the National Oceanic and Atmospheric Administration (NOAA) on rainfall for five years prior to sampling at NPS well locations, and on drought conditions, as estimated by NOAA using the Palmer Drought Index.

- **Data on physical/chemical characteristics of pesticides**. EPA obtained values for physical/chemical properties of pesticides -- half life and K_{oc} -- from data collected by EPA's Office of Pesticide Programs.

- **Data developed by other surveys of pesticides or nitrate in ground water or well water**. EPA reviewed the reports of selected recent surveys, including the National Alachlor Well Water Survey and four state surveys, to identify similarities and differences among the reported results.

Associations Evaluated

EPA carried out over a thousand statistical tests evaluating hypotheses about the association of pesticides and nitrate in drinking water wells with many different variables. These analyses included:

- Studies of the association between detections of NPS analytes in drinking water wells and Agricultural DRASTIC scores and subscores for county-level and for sub-county level evaluations of the sensitivity of ground water to contamination.

- Studies of the association between detections in wells and drinking water well characteristics, reports of pesticide and fertilizer use on or near the property where the well is located, farming and animal husbandry near wells, the presence of surface water, and other variables derived from questionnaire data. Two categories of data that were not gathered and therefore were not included in the analysis are data on the ground-water flow and recharge area for wells and data on the soil profile near wells.

- Studies of the association between detections in wells and estimates of nitrogen fertilizer and pesticide use and surrogate measures of agricultural activities and livestock operations derived from data obtained by EPA from non-NPS sources such as the Census of Agriculture.

- Studies of the association between detections in wells and the physical/chemical characteristics of pesticides and ground water in the drinking water wells sampled. The Survey did not collect data that would allow analysis of soil composition and chemistry near the sampled drinking water wells.

- Studies of the association between detections in wells and measures of precipitation and drought.

Individual results from these analyses were grouped according to their relationship to five factors considered to affect well water contamination.

- **Sensitivity** is defined for this review of the analytic results as the intrinsic susceptibility of an aquifer to contamination. Sensitivity addresses the hydrogeologic characteristics of the aquifer and the overlying soil and geologic materials, and is unrelated to agricultural practices, well construction, or pesticide characteristics.

- **Pesticide and fertilizer use** is defined for the NPS Phase II analysis as the scope and amount of pesticides and nitrogen fertilizers applied near sampled drinking water wells, and activities, such as cattle raising, that could contribute to the presence of pesticides or nitrate in places where they could be transported into drinking water wells.

- **Transport** is defined as factors that contribute, either directly or indirectly, to the movements of pesticide and nitrate by water, including precipitation, irrigation, surface water, drainage ditches near the well, other bodies of water such as rivers and lakes, and nearby operating wells. This definition is narrower than customary definitions of transport, since it does not include recharge or ground-water flow. It applies only to the NPS Phase II analysis.

- **Chemical characteristics** are defined as characteristics of pesticides, such as organic partition coefficients (K_{oc}) and half-life, and characteristics of well water, such as water temperature, pH, and conductivity, that could affect the behavior of pesticides or nitrate.

- **Physical characteristics** of wells, are defined as age, depth, state of repair, and protective devices, such as concrete pads, that could affect the presence of chemicals in the well.

Evaluation Criteria

The results reported in Phase II have been evaluated in the context of several criteria, including the accuracy, area of geographic coverage, and the time period in which the data were collected; the statistical significance of the results, the size of the effect, the sample size, and patterns of results within the survey and the comparison of results between NPS and other studies. The reported results should not be interpreted as conclusions drawn from controlled experiments or as evidence of causation. The results are statistical measures of association or correlation that were designed to test hypotheses developed from several scientific and policy questions. The results should be used with caution, as indicators of topics that may be suitable for further careful investigation and as information to supplement interpretation of previous studies. In several cases, results that would have been expected, on the basis of other studies or theoretical understanding of the processes involved, were not identified by the NPS Phase II analysis. Because of the many limits on the analysis, this should not be taken as an indication that such factors are not important.

Key Results of Analysis of Single Variables

Key results for tests of association between detections in drinking water wells and individual factors came primarily from analysis of nitrate detections in CWS wells. The relatively large number of associations involving nitrate detections is partly due to the fact that a significantly larger number of nitrate detections than pesticide detections were obtained. These key results include:

Sensitivity

- The Survey's county-level and sub-county level Agricultural DRASTIC assessments did not prove to be a useful means of locating drinking water wells containing pesticides or nitrate. Although DRASTIC did help to ensure that the Survey achieved broad national coverage, total DRASTIC scores were not found to be related to pesticide or nitrate detections. The failure of DRASTIC scores to be positively associated with pesticide detections in drinking water wells is not a measure of the validity of the DRASTIC method. EPA used a simplified and cost-effective procedure to collect information for DRASTIC evaluations at the county level. The NPS was not designed or implemented as a scientific test of DRASTIC. The NPS was designed to use DRASTIC as a method to characterize counties in relatively more or less vulnerable settings.

- Different DRASTIC factors often were associated with detections in CWS wells than were associated with detections in rural domestic wells. County-level depth to water table was associated with pesticide detections, and county-level hydraulic conductivity was associated with nitrate detections in CWS wells. Accurate DRASTIC measurements for specific well locations are not possible using county-level scores. For example, intra-county variability is lost in county-level scoring. At the sub-county level, different types of vadose zone media were associated with pesticide detections in CWS wells.

- Stratification based on combined Agricultural DRASTIC scores and county cropping patterns (the "cropped and vulnerable" strata) was not effective in improving the precision of the Survey results. The Phase II analysis did not demonstrate a relationship between stratification variables and pesticide or nitrate detections. Oversampling of certain strata in future surveys should be undertaken only if the criteria used are known to be closely associated with detections and can be measured with sufficient accuracy to improve the survey estimates and precision.

Use of Pesticides and Nitrate

- The Survey's data on pesticide use, collected both from local landowners and from experts on local cropping and agrichemical uses, in many cases did not indicate that pesticides had been used within the previous 3 or 5 years near wells where they were detected. These data, collected for the area within 300 or 500 feet of the well or within one-half mile of the well, depending on the question and respondent, may not have adequately reflected pesticide use within the recharge area for the well.

- Measures of agronomic activity based on state-level data, including the market value of crops and livestock produced in the county where the well is located, were associated with detections, particularly for nitrate.

- The degradates of the pesticide DCPA were detected in both CWS wells and rural domestic wells. The amount of DCPA use on golf courses and in urban applications was related to the possibility of detecting DCPA acid metabolite in CWS wells and rural domestic wells, based on extrapolations of regional data on DCPA use.

Transport

- Variables relating to transport of chemicals to ground water provide suggestive evidence concerning the processes affecting contamination. Nitrate detections were more likely in CWS wells drawing water from an unconfined aquifer. The presence of surface bodies of water near sampled wells generally was associated with a reduced likelihood of detections.

- Survey results suggest that there is a lower probability of detecting pesticides or nitrate in wells in counties that experienced high levels of rainfall. The result suggests that high levels of rainfall may cause the pesticides to run off before entering ground water or to dilute the concentration of pesticides and nitrate to the point that they fall below the detection limits used by the Survey. In contrast, flood irrigation was associated with a greater likelihood of detection.

- Evaluation of the associations between detections in drinking water wells and Palmer Drought Index scores prepared by the National Oceanic and Atmospheric Administration provided evidence that nitrate concentrations are lower in wells in moist regions.

Chemical Characteristics

- The likelihood of detecting pesticides or nitrate is greater in wells with low water temperature or low water pH.

- The likelihood of *detecting* nitrate is greater in wells delivering water with low electrical conductivity. Higher conductivity of well water was found to correspond to higher nitrate *concentrations*.

- The Survey examined the association of pesticide persistence, based on half-life in soil, with detections. Persistent pesticides were more likely to be detected in drinking water wells than pesticides with short half-lives.

- Estimates of concentrations for the chemicals most frequently detected in the NPS suggest that there is a significant percentage of wells containing concentrations of pesticides or nitrate below the MRLs that might have been detected without such limits.

Well Construction and Condition

- Shallower wells were associated with nitrate detections in both CWS and rural domestic wells and with pesticide detections in CWS wells. An association was also found between detections of nitrate in rural domestic wells and older wells.

Results of Multivariate Analyses

The Phase II analysis carried out multivariate regression analyses to determine if combinations of variables would be particularly strong predictors of pesticide and nitrate contamination of drinking water wells. Because of the relatively small number of pesticide detections and substantial commonality among variables, however, the predictive value of many of the factors considered in the analysis was difficult to evaluate. Very few variables appeared in more than one model. The best models were identified on the basis of how well they fit the data. The appearance of different variables in the models does not necessarily reflect physical or theoretical interchangeability of the variables.

For pesticide detections, two variables -- fertilized pasture and rangeland, measured at the county level, and well depth -- created the best model for detections of a pesticide in CWS wells. The presence of other operating wells near the sampled wells can be used in place of the well depth variable without substantially reducing model performance. An indirect measure of agricultural activity -- market value of crops in thousands of dollars -- by itself was the best model for pesticide detections in rural domestic wells. A variable measuring the number of beef cattle per acre could also be included.

For *nitrate detections in drinking water wells*, a three-variable model, composed of fertilized pasture and rangeland, average monthly precipitation, and well-water pH, created the strongest results for nitrate detections in CWS wells. Farming on the property where the well is located also can be included in the model. A four-variable model, composed of well age, maximum monthly precipitation in the five years prior to sampling, well water pH, and the presence of an unlined drainage ditch within less than one-half mile, created the best model for nitrate detections in rural domestic wells. A variable for fertilized pasture and rangeland could also be included.

For *nitrate concentrations* in CWS wells, five variables -- maximum monthly precipitation in the past five years, well water electrical conductivity, total nitrogen sales by county for counties containing wells in which nitrate was detected, well depth, and a categorical variable that reflects the Palmer Drought Index score for the year prior to sampling -- create the best model. Crop value can be used in place of total nitrogen sales without substantially reducing model performance. For nitrate concentrations in rural domestic wells, four variables are included in the best model -- well depth, market value of crops, presence of an unlined body of water within one-half mile, and the Agricultural DRASTIC subscore for topography measured at the sub-county level. Total nitrogen sales can be used in place of crop value. A variable for the presence of a body of water within 300 feet of the well could also be included.

Results of Population Exposure Analysis

The Phase II analysis prepared estimates of concentration distributions in drinking water wells for DCPA acid metabolites and nitrate. Based on these concentration estimates, the frequency of occurrence of these chemicals in CWS wells and rural domestic wells is somewhat higher than presented in the NPS Phase I Report based on national estimates that were calculated from concentrations that exceeded minimum reporting limits. Quantitative exposure estimates prepared for DCPA acid metabolites and nitrate using these concentration estimates suggest that current potential health effects are low for these analytes detected most frequently in the Survey. This result confirms the similar conclusion reached in the Phase I Report that Survey results do not demonstrate any immediate widespread health concern.

Approximately 19 million people are estimated to be exposed to nitrate in rural drinking water wells, with about 1.5 million exposed to levels of nitrate over the Maximum Contaminant Level of 10 mg/L (ppm), and approximately 22,500 infants under 1 year old exposed to a concentration of greater than 10 mg/L.

Persons with high levels of nitrate in their private wells should consult their pediatricians and may wish to obtain water from alternate sources that have less than 10 mg/L of nitrate to help protect infants from the risk of methemoglobinemia (blue-baby syndrome). Physicians are usually well informed about the risks to infants of high levels of nitrate in drinking water and are able to provide medical treatment. Approximately 85 million people are estimated to drink water from CWS wells that contain nitrate, with about 3 million exposed to levels of nitrate over 10 mg/L (ppm), and approximately 43,500 infants under 1 year old exposed to a concentration of greater than 10 mg/L. Public water supplies that violate the Maximum Contaminant Level of 10 mg/L for nitrate are required to notify their customers about the violation, and the adverse health effects caused by nitrate. (40 CFR 141.32) Local and state health authorities are the best source for information concerning alternate sources of drinking water for infants. Systems that apply for variances or exemptions while in violation of the standard may be required by the state to provide bottled water or point-of-use or point-of-entry devices to avoid unreasonable risks to health. (40 CFR 141.62(f))

Results of Individual Risk Analysis

EPA estimates that about 10.4 percent of CWS wells and 4.2 percent of rural domestic wells contain detectable levels of one or more pesticides. The Phase II study estimated the chance that a well that contains one or more pesticides also exceeds a maximum contaminant level or health advisory. EPA estimates that no more than 7.3 percent of the 10.4 percent of CWS wells that contain one or more pesticides could exceed an MCL or health advisory. Similarly, no more than 28.3 percent of the 4.2 percent of rural domestic wells that contain detectable levels of one or more pesticides are also expected to exceed a health based limit. In summary, about 1 percent of all drinking water wells in the U.S. are estimated to exceed a health based limit. EPA concluded that the overall chance of a given well exceeding a level of concern for a pesticide is low. If a well contains a detectable amount of one or more pesticides, it has a slightly higher risk of also exceeding a health based limit. EPA recommends that well owners that know or suspect that their well is affected by pesticides have the water tested to ensure that any pesticides are present at levels below the MCLs or health advisories.

Recommendations for Future Studies

The NPS was the first survey of the presence of pesticides and nitrate in public and private drinking water wells throughout the United States. Its results provide several useful lessons for the design of future studies. The Survey design functioned effectively to produce the data upon which the Phase I national population estimates were based. To provide the best data for complex statistical analysis of results of future surveys, however, four topics should be carefully evaluated.

First, features such as stratification should be used to control for possible factors that may confuse or confound results, but the stratification variables must be known to have a substantial effect on what is being measured. Oversampling of selected strata should be carried out only if the variables that define the strata can be defined and measured with accuracy.

Second, pilot studies should test and evaluate statistical analysis approaches.

Third, the specifications for survey size and precision and the limits established in chemical analytic procedures for reporting detections (such as minimum reporting limits) should be chosen to ensure that a sufficient number of detections are likely to be obtained to support complex data analysis and statistical modelling of the survey data. All laboratory results should be reported. Laboratory analyses must include confirmation steps. The laboratory should then report the data with sufficient information to judge the reliability of the reported concentration. For example, results reported below the minimum reporting limit must be flagged to alert the data user to the inherent variability of concentrations reported at such low levels. The frequency of detection of DCPA acid metabolites confirms the importance of considering pesticide metabolites in survey design.

Fourth, site-specific data on ground-water sensitivity and pesticide use should be obtained. Data on the recharge patterns for particular wells should be investigated. Locally precise pesticide use and distribution data should include non-farm as well as farm pesticides, and data should be gathered on both farm and non-farm uses of fertilizers. The data, which should be publicly available, will help to ensure that assessments of the vulnerability of drinking water wells to contamination can be improved and made more reliable.

The Survey analysis also identified a number of additional topics for future study. They include studies of seasonal and temporal effects on contamination, analysis of links between surface and ground-water contamination, and collection and evaluation of site-specific data on soil characteristics and recharge and their association with contamination patterns in wells.

In summary, the National Pesticide Survey provides useful national information for the formulation and improvement of policies to protect drinking water wells from contamination by pesticides and nitrate. The results suggest that many interacting factors affect the quality of drinking water wells.

Chapter One: Introduction

The U.S. Environmental Protection Agency's National Survey of Pesticides in Drinking Water Wells (the National Pesticide Survey, the Survey, or NPS) was designed to determine the frequency and concentration of the presence of pesticides and nitrate in drinking water wells in the United States. The Survey's Phase I Report[1] addressed this objective. The Phase I Report provides estimates of the number and proportion of community water system (CWS) wells and rural domestic wells nationwide containing detectable levels of 126 pesticides and pesticide degradates, plus nitrate. The Phase I Report also contains summary estimates of drinking water well characteristics derived from questionnaire responses.

Survey results provide an opportunity to examine how detections of pesticides and nitrate in drinking water wells are associated with a number of factors that could affect their presence in well water. In Phase II of the Survey analysis, EPA carried out studies of associations between analyte detections in wells and measures of the vulnerability of the wells' water to contamination; patterns of pesticide and fertilizer use near wells; current and previous uses of property surrounding wells; hydrology; terrain and other natural features near wells; depth, age, location, and construction of wells; and other factors. This Phase II Report has been prepared for readers with a good understanding of statistics and fate and transport mechanisms in ground water. It describes the data sources and analytic approaches used in Phase II; the key results of the analysis, along with discussions of the statistical, scientific, or agronomic basis for their significance; and a discussion of the Survey's implications for potential future analyses of similar issues. It also provides recommendations, based upon the experience gained in the implementation of the Survey and analysis of its results, for future work and for implementation of ground-water protection programs.

1.1 Review of Survey Implementation and Phase I Results

The National Pesticide Survey is a joint project of EPA's Office of Ground Water and Drinking Water (OGWDW) (formerly the Office of Drinking Water) and Office of Pesticide Programs (OPP). Survey design began in 1984. The design of the Survey was reviewed and endorsed by a special subpanel of EPA's independent Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) Scientific Advisory Panel. EPA conducted a pilot study in California, Mississippi, and Minnesota in 1987 to test Survey implementation and analytical procedures. After extensive planning and preparation, full scale sampling for the National Pesticide Survey began in April 1988. The final sample was collected in February 1990. Wells were sampled in every State, and extensive data were collected about the wells' physical characteristics, in addition to surrounding circumstances such as nearby pesticide use and agricultural activities.

EPA tested well water from two kinds of wells: wells at community water systems and rural domestic wells. Community water systems are defined as systems of piped drinking water with at least 15 connections or serving at least 25 permanent residents. To be eligible for the Survey, a system had to have at least one operable well, at the time of sampling, that supplied drinking water. Rural domestic wells are defined as drinking water wells supplying water for human consumption (drinking, cooking, or bathing) to an occupied private household located in a rural area of the United States. Rural areas are defined as households outside of incorporated or unincorporated places with a population of 2,500 or more and outside of urban areas.

A multistage stratified selection procedure was used to choose a nationally representative subset of CWS wells and rural domestic wells for sampling. The results provide a national estimate and are not representative of any State or local area. In choosing wells, EPA first characterized all counties in the U.S.

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[1] National Survey of Pesticides in Drinking Water Wells, Phase I Report (EPA 570/9-90-015, November 1990) (hereafter NPS Phase I Report). Copies may be obtained from the National Technical Information Service, Springfield, Virginia 22161 (1-800-336-4700) for $35 plus $3 handling. Request report number PB91-125765.

according to proxies for pesticide use and relative ground-water vulnerability[2] ("first-stage stratification"). Agricultural pesticide use was specified as high, moderate, low, or uncommon. EPA specified areas of greater and lesser relative ground-water vulnerability by using a numerical classification system called DRASTIC, which considers seven factors that may affect the vulnerability of ground water to contamination. The Survey design called for a specified number of wells to be sampled from areas of greater and lesser pesticide use and ground-water vulnerability.

To identify CWS wells, EPA randomly selected 7,083 community water systems from a list containing information on all public water supply systems. EPA conducted telephone interviews with representatives of the 7,083 selected systems and, based on the results of the screening process, identified systems eligible for sampling. Water samples from 566 eligible CWS wells in 50 States were collected. The 540 samples that passed quality assurance requirements were used in data analysis. When selecting rural domestic wells, EPA randomly chose 90 counties located in 38 States as areas for sampling to represent the nation's wide range of agricultural pesticide use and ground-water vulnerability. EPA assessed ground-water vulnerability within sub-county areas and collected information from county agricultural extension agents on cropping intensity to further subdivide the counties into areas that are more or less vulnerable to pesticide contamination in ground water ("second-stage stratification"). Water samples from 783 eligible rural domestic wells were collected. The 752 samples that passed quality assurance requirements were used in data analysis.

Once the wells were selected, EPA scheduled sample collection so that wells were visited throughout the 22 month sampling period from April 1988 to February 1990. This schedule provided well water samples during all seasons and pesticide application cycles. This approach was used to minimize the effect that seasonal variability may have on concentrations of pesticides or nitrate in drinking water wells.

EPA visited each well once, filling a sufficient number of sample bottles with well water to carry out chemical analyses and QA/QC procedures. At each well sampled, questionnaires were used to collect data, including:

- observations about the well and the surrounding area;
- information from the owner/operator about well construction and agricultural and non-agricultural pesticide use on the property where the well was located; and
- information from county agricultural extension agents, who were knowledgeable about local crops, pesticide use, and land use within one-half mile of the well.

Each water sample gathered in the National Pesticide Survey was tested for 127 analytes. Eight chemical analytical methods (seven organic and one inorganic) were required. All positive detections of organic analytes were confirmed by reanalyzing on a second (different) capillary gas chromatographic (GC) column or a high performance liquid chromatographic (HPLC) column. These analyses provided both a preliminary qualitative confirmation for all GC determinations and the final confirmation for HPLC analyses. The analytes detected using a GC based method also were qualitatively confirmed using gas chromatography/mass spectrometry (GC/MS). Ten percent of the well's samples were sent to referee laboratories to determine the occurrence of false negatives. The measured concentration of the primary analysis of confirmed detections was the concentration reported.

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[2] When the stratification was carried out, the term "vulnerability" was used to describe the intrinsic susceptibility of an aquifer to contamination, based on the hydrogeologic characteristics of the aquifer and the overlying soil and geologic materials. EPA now uses the term "sensitivity" to refer to intrinsic susceptibility, and considers aquifer vulnerability to be a more comprehensive term, encompassing the susceptibility of an aquifer to contamination from the combined effects of its sensitivity, agricultural practices, and pesticide characteristics. In this report, the term vulnerability has been used when it refers to activities undertaken at the time EPA used the term and to variables developed as a result. Thus, stratification is discussed in terms of vulnerability because that term was used when stratification was carried out and results are reported for DRASTIC scoring and assessments of vulnerability. The term sensitivity is used to report the evaluation of the Phase II analyses because it represents the current concept that was analyzed. Irrespective of the term used, it must be noted that the NPS is a survey of drinking water wells, not of ground water.

EPA established a minimum quantification limit (MQL) and a minimum reporting limit (MRL) for each analyte. The MQL was based on the precision of the method and the sensitivity of the analytical instrumentation. MQLs were established with concentrations for 112 of the analytes. Analyses of the remaining 15 analytes were classified as unreliable because of the instability of the analytes in water or other factors. The Agency chose to look for the presence of these analytes and only report them as "positive detections," (i.e., if detected, their presence was reported to the well owner, but no concentration level was reported). These "positive detections" were not included in the estimates presented in the Phase I report or the other statistical analyses conducted for the Phase II report. Measured concentrations below the MQL, down to a concentration of one-half the MQL, were not considered as reliable and also were reported as "positive detections" but without a concentration level. The cutoff point of one-half the MQL was called the minimum reporting limit (MRL). No detections or concentrations were reported below the MRLs.

The NPS sampled 1349 CWS wells and rural domestic wells for the presence of 101 pesticides, 25 pesticide degradates, and nitrate (measured as N) (127 analytes). In all, 17 analytes were detected in the Survey. Thirteen were detected at levels above the NPS minimum reporting limits (MRLs) used by the primary laboratories that performed the initial analysis of samples; three (alpha-chlordane, gamma-chlordane, beta HCH) were detected by EPA laboratories at concentrations lower than the respective primary laboratory MRLs. The concentration of one detected chemical (4-nitrophenol) could not be measured.

Exhibits 1-1 and 1-2 show the estimates generated in Phase I of the number and percent of wells of the estimated 94,600 CWS wells and the 10.5 million rural domestic wells in the U.S. containing each of the 13 chemicals detected at concentrations above the Survey's MRLs.[3] EPA estimated that about 10.4 percent of the CWS wells nationwide (approximately 9,850 wells, although the number could be as high as 13,400 wells or as low as 6,300 wells, based on the upper and lower 95% confidence bounds) and 4.2% of rural domestic wells (approximately 446,000 wells, although the number could be as high as 647,000 wells or as low as 246,000 wells) contain detectable levels of one or more pesticides included in the Survey.

As the Phase I Report stated, the number of wells containing pesticides or nitrate could differ from these results. Local or regional areas with particularly high or low levels of chemicals may not have been randomly chosen for sampling and additional chemicals might have been present in the wells sampled, at levels too low to be reported as detections by the Survey.

A detailed description may be found in the NPS Phase I Report of the Survey design and implementation, national estimates of the number of wells containing NPS analytes, summaries of data derived from the Survey questionnaires, and copies of the questionnaires. Knowledge of those topics is necessary for complete understanding of the Phase II results.

1.2 Phase II

The Phase II analysis used data collected during the Survey and data from other sources to investigate the relationship of pesticide and nitrate detections to five general factors. These factors are:

- Ground Water Sensitivity -- the intrinsic susceptibility of an aquifer to contamination, which addresses the hydrogeologic characteristics of the aquifer and the overlying soil and geologic materials, but is not related to agricultural practices or pesticide characteristics;

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[3] NPS Phase I Report, p. 61. The MRL for each Survey analyte is provided in Appendix E of the Phase I Report.

Exhibit 1-1

Estimated Number and Percent of Community Water System Wells Containing NPS Analytes

Analyte	Estimated Number	95% Confidence Interval (lower - upper)	Estimated Percent	95% Confidence Interval (lower - upper)
Nitrate	49,300	(45,300 - 53,300)	52.1	(48.0 - 56.3)
DCPA acid metabolites	6,010	(3,170 - 8,840)	6.4	(3.4 - 9.3)
Atrazine	1,570	(420 - 2,710)	1.7	(0.5 - 2.9)
Simazine	1,080	(350 - 2,540)	1.1	(0.5 - 2.7)
Prometon	520	(78 - 1,710)	0.5	(0.1 - 1.8)
Hexachlorobenzene*	470	(61 - 1,630)	0.5	(0.1 - 1.7)
Dibromochloropropane (DBCP)*	370	(33 - 1,480)	0.4	(0.1 - 1.6)
Dinoseb*	25	(1 - 870)	<0.1	(<0.1 - 0.9)

* Registration canceled by EPA.

Exhibit 1-2

Estimated Number and Percent of Rural Domestic Wells Containing NPS Analytes

Analyte	Estimated Number	95% Confidence Interval (lower - upper)	Estimated Percent	95% Confidence Interval (lower - upper)
Nitrate	5,990,000	(5,280,000 - 6,700,000)	57.0	(50.3 - 63.8)
DCPA acid metabolites	264,000	(129,000 - 477,000)	2.5	(1.2 - 4.5)
Atrazine	70,800	(13,300 - 214,000)	0.7	(0.1 - 2.0)
Dibromochloropropane (DBCP)*	38,400	(2,740 - 164,000)	0.4	(<0.1 - 1.6)
Prometon	25,600	(640 - 142,000)	0.2	(<0.1 - 1.4)
Simazine	25,100	(590 - 141,000)	0.2	(<0.1 - 1.3)
Ethylene dibromide*	19,200	(160 - 131,000)	0.2	(<0.1 - 1.2)
Lindane	13,100	(14 - 120,000)	0.1	(<0.1 - 1.1)
Ethylene thiourea	8,470	(1 - 111,000)	0.1	(<0.1 - 1.1)
Bentazon	7,160	(1 - 109,000)	0.1	(<0.1 - 1.0)
Alachlor	3,140	(1 - 101,000)	<0.1	(<0.1 - 1.0)

* Registration canceled by EPA.

- Agricultural Activity and Pesticide and Fertilizer Use -- the scope of agricultural and non-agricultural use of pesticides and nitrogen fertilizers and the scope of agricultural practices, that could contribute to the presence of pesticides or nitrate in well water;

- Transport -- factors that contribute, either directly or indirectly, to the movement of pesticides and nitrate, such as precipitation;

- Chemical Characteristics -- factors that are characteristic of pesticides (K_{oc}, half life), and factors that are characteristic of the soil or ground water in the sampled wells (temperature, pH, conductivity); and

- Physical Characteristics of Wells -- factors that are characteristic of wells (depth, age, construction).

EPA specified an initial set of hypotheses to focus the Phase II analysis on important scientific or policy questions. These hypotheses are shown in Exhibit 1-3. EPA tested these hypotheses and conducted exploratory analyses using a variety of data analysis methods that are described in Chapter 2. Chapter 3 describes the significant findings for specific variables.

Nitrate, DCPA acid metabolites, and atrazine are the three most frequently detected analytes in both community water system wells and rural domestic wells. Both DCPA (Dacthal), the parent compound of DCPA acid metabolites, and atrazine were registered for use in the late 1950s. The uses of the two chemicals, however, are substantially different. DCPA is used to control annual grasses and broadleaf weeds in turf and on ornamentals and a number of fruits and vegetables, as well as cotton, soybeans, and field beans. It has both agricultural and non-agricultural uses. Atrazine, in contrast, is most frequently used for agricultural applications, particularly on corn, sorghum, sugarcane, and for weed control on non-cropped and fallow land. In general, pesticides, including atrazine and DCPA acid metabolites, were detected more frequently in CWS wells than in rural domestic wells, which is contrary to the expectations upon which the Survey was designed. The concentrations of pesticides were generally lower in CWS wells than in rural domestic wells. The high concentrations found in rural domestic wells were substantially higher than the high concentrations found in CWS wells, except for DCPA acid metabolites. A number of questions that arise from these results were examined in Phase II, including whether the Survey data provide an explanation for the difference between CWS and rural domestic well findings and whether explanations for the relatively large numbers of DCPA acid metabolite and atrazine detections can be developed and tested. EPA also examined the degree of similarity between the NPS results and results obtained by other studies of pesticides and nitrate in drinking water wells.

The analyses performed in Phase II are limited by the following:

- On a national scale, contamination of drinking water wells by any given pesticide is, fortunately, relatively infrequent. The reliability with which any relationship between detection and another factor can be estimated depends on the frequency of detections. As discussed in detail in Chapter 2, the only individual NPS analytes with sufficient detections for reliable statistical analysis are nitrate in CWS wells and rural domestic wells and DCPA acid metabolites for CWS wells. Other analyses are based on a subset of all the analytes consisting of all pesticides detected by the primary analytic laboratories.

- The Phase II analyses identify factors that are potentially useful topics for additional detailed research and provide information to be considered together with the results of previous studies. The Phase II analyses are not designed to provide results that are suitable by themselves to serve as the basis for policy development.

Exhibit 1-3

Hypotheses Tested in the NPS Phase II Analyses

Ground-Water Sensitivity

- Analytes are detected more frequently in counties with high DRASTIC scores.
- Analytes are detected more frequently in areas where aquifers are more vulnerable to contamination.
- Analytes are detected more frequently in vulnerable areas if the area is also cropped.

Pesticide and Nitrogen Fertilizer Use

- Analytes are detected more frequently in areas with high pesticide use.
- There is a significant difference in analyte detection by month or season.
- Analytes are detected more frequently in areas with pesticide use within one-half mile of the well.
- Analytes are detected more frequently in areas of pesticide use if the area is also an area of high vulnerability.
- Analytes are detected more frequently in areas where non-farm pesticides are used.
- Detection of nitrate is a good indicator of pesticide contamination.
- Crops or crop types are good indicators of pesticide or nitrate contamination.
- Point sources of contamination (septic tanks, pesticide spills, pesticide and fertilizer dealerships, and disposal sites) are good indicators of contamination.
- Analytes are detected more frequently in areas of livestock production (high acreage in pasture, feed lots).

Transport

- Analytes are detected more frequently in wells tapping unconfined aquifers.
- Analytes are detected more frequently in areas where irrigation is used.
- Analytes are detected more frequently in areas with greater precipitation.

Chemical Characteristics

- Analytes are detected more frequently if they are mobile (low K_{oc} values) and persistent (long biodegradation and hydrolysis half-lives).
- Analytes are detected more frequently in wells with low water temperature.
- Analytes are detected more frequently in wells with water with low pH.
- Analytes are detected more frequently in wells with water with high electrical conductivity.

Physical Characteristics

- Analytes are detected more frequently in shallow and/or not optimally constructed and/or old wells.

- The Survey's statistical design was chosen to provide national estimates of wells containing pesticides or nitrate. The choice of wells to be sampled and the number of water samples obtained were not designed specifically to test the hypotheses investigated in the Phase II analyses. The Phase II analysis was unable to test or control for many confounding factors that are known to influence pesticide occurrence in drinking water wells. What is understood about the mechanisms involved in well water contamination suggests that the process is quite complex, involving many factors, including some factors that were not measured by the NPS. In general, the NPS collected data on many of the most important factors generally considered to affect ground-water and well water contamination. Very little data is available on other factors, such as soil types and characteristics in areas of pesticide application near tested wells, recharge areas of tested wells, and well location up-gradient or down-gradient of pesticide or fertilizer use areas.

- The NPS is a one-time "snapshot" of the nation's community water system wells and rural domestic drinking water wells. The presence and concentrations of pesticides and nitrate in drinking water wells are thought to vary temporally and spatially. Temporal variation involves a complex interaction among rainfall patterns, crop life cycles, pesticide and fertilizer application patterns, and local soil characteristics. This pattern may vary regionally. As a one-time sample, however, the NPS cannot reliably estimate any temporal trends. In addition, because the NPS is a "snapshot," the number of wells containing pesticides and nitrate may differ over time from the number estimated from NPS results. As a national sample, too few wells were sampled in each region of the country to perform regional studies.

- The Phase II analysis does not address causation. A statistical association between two variables by itself does not imply that one causes the other. Unambiguous attribution of causality generally requires not just a statistical association, but also a plausible causal mechanism. An observational study, such as the NPS, cannot alone provide proof of causality.

- The Survey followed stringent quality assurance/quality control procedures in the collection of questionnaire data as well as in chemical analyses. In a few cases, the quality of the data for factors that were measured by the NPS questionnaires may have been reduced as a result of measurement error, respondent error, or for other reasons. The QA/QC results for the chemical analyses presented in Appendix D to the Phase I report indicate that those data meet all QA/QC standards. When pertinent, this Report discusses the quality of the data used in the analyses.

The balance of this Phase II Report consists of four chapters:

- Chapter Two describes the data sources and statistical approaches used to investigate the extent to which analyte detections are associated with factors such as ground-water vulnerability, pesticide or fertilizer use, and a number of other characteristics;

- Chapter Three presents the results of statistical analyses organized by data sources. Appendix A reports additional results that did not fully satisfy statistical screening criteria but that may be useful to help identify trends or to stimulate additional research;

- Chapter Four summarizes the results of the analyses reported in Chapter 3 in the context of the four key factors thought to affect contamination, and compares the findings to those of previous studies as well as other selected surveys. Chapter Four also presents the results for multivariate regression analyses, estimates of concentration distributions for the most frequently detected analytes, and exposure estimates for those analytes; and

- Chapter Five presents the major conclusions of Phase II and makes several recommendations for future environmental monitoring work.

Chapter Two: Data Sources and Statistical Approach

This chapter describes the data sources used in the Phase II analysis and the statistical techniques used to perform the analyses.

2.1 Data Sources

The Phase II analysis used several types and sources of data, including pesticide and nitrate detections; measures of ground-water vulnerability and pesticide use developed during the stratification process that preceded selection of the wells to be sampled; information from questionnaires administered at the time of well sampling; and data on precipitation and drought, pesticide use, and potential sources of nitrate such as fertilizer use and animal husbandry. As Exhibit 2-1 indicates, the scope of the data extended from broad regional or state-wide aggregation to a narrow focus on individual wells or areas in close proximity to wells. Exhibit 2-2 provides the sources for each category of data.

Exhibit 2-1

Type and Scope of Data Used in Phase II Analysis

	EPA Region	State	County	Sub-County	Well or Well Area	Chemical
Analyte Detections					●	
Precipitation			●	●	●	
Ground-Water Vulnerability			●	●	●	
Pesticide Use	●	●	●	●	●	
Fertilizer Use		●	●		●	
Farming Activities			●	●	●	
Non-Farming Activities	●			●	●	
Well Construction/Conditions					●	
Well Water Characteristics					●	
Pesticide Characteristics						●

Well or well area data were all generated by the NPS. Analyte detection data came from the chemical analysis of well water samples; well water characteristics data (temperature, pH, electrical conductivity) were collected during sampling; all other well-level data were collected from Survey questionnaires. Sub-county level data, corresponding to areas larger than the immediate vicinity of the well but smaller than a county, includes data from weather stations, data used in defining "cropped and vulnerable" areas, and questionnaire data. County-level data includes data used for first-stage stratification, and data from the Census of Agriculture. In addition, as described in Sections 2.1.4 and 2.1.5 of this chapter, as well as in Chapter 3, county-level measures were developed from regional and state-level data. Regional and state-level data included estimates of pesticide use and nitrogen fertilizer sales.

Exhibit 2-2

Sources of Data Used in Phase II Analysis

	NPS Questionnaires	NPS DRASTIC Scoring and Stratification	NPS Well Sampling	NPS Chemical Analyses	NOAA	U.S.D.A. Census of Agriculture	Resources for the Future	NFERC/EPA Fertilizer Sales Data	EPA Pesticides Database
Analyte Detections				●					
Precipitation and Drought					●				
Ground-Water Vulnerability	●	●	●						
Pesticide Use	●	●					●		
Fertilizer Use	●	●						●	
Farming Activities	●	●				●		●	
Non-Farming Activities	●								
Well Construction/ Conditions	●		●						
Well Water Characteristics	●		●	●					
Pesticide Characteristics									●

2.1.1 Laboratory Analytical Data

An analytical results data file was created for the Phase II analysis for individual analytes and groups of analytes. Analytes with less than five detections were included in analyses of selected groups of chemicals but individually could not be used for statistical analysis.[1]

Background on the analytical results data file is provided in the NPS Phase I Report. The procedures followed by the NPS for selecting the chemical analytic procedures, establishing minimum quantification limits and minimum reporting limits, carrying out confirmation of positive detections, and performing quality control are described in Chapters 4 and 5 of the Phase I Report. Appendix E of that report lists each Survey analyte, along with the minimum quantification limit for that analyte. Appendix E also provides data on the numbers of analyses deleted due to failure to meet quality control guidelines; results for laboratory control standards fortified at 10 times the MQLs; a comparison of the results for laboratory control standards and for spiked field samples; and a false negative rate for each analyte.

2.1.2 Ground-Water Vulnerability Characteristics

To analyze the influence of ground-water vulnerability characteristics, NPS collected data using the Agricultural DRASTIC scoring system and questionnaires that obtained information on land features and aquifer type.

DRASTIC scoring. During the implementation of the statistical design of the Survey, EPA obtained data on hydrogeological conditions throughout the nation at the county level and for sub-county areas of 90 counties. Although these data were obtained initially to carry out stratification, they were also used in Phase II of the Survey to test the success of stratification in identifying vulnerable areas as well as to test other hypotheses about ground-water vulnerability and contamination.

Hydrogeological data from sources such as State geologic survey reports and United States Department of Agriculture Soil Conservation Service soil surveys were used to derive county-level scores for each of the 3,137 counties or county equivalents in the U.S. Prior to sampling, each county was assigned to the category of relatively high, moderate, or low ground-water vulnerability (first-stage stratification) on the basis of its Agricultural DRASTIC classification.[2] This was done for each county by characterizing the seven hydrogeologic parameters of DRASTIC: depth to water, recharge (net), aquifer media, soil media, topography (slope), impact of vadose (unsaturated) zone, and conductivity (hydraulic) of the aquifer. These county-level DRASTIC first-stage data do not account for site-specific detail such as topography, well depths, and soils. A dataset was created that identified the seven hydrogeologic subscores and the total weighted score for each county.

In order to obtain ground-water vulnerability information at a more refined spatial scale for the sampling of rural domestic wells, the 90 counties selected for rural domestic well sampling were divided into sub-county regions with common hydrogeologic settings. DRASTIC scores and subscores were then derived for these sub-county regions. Because the sub-county DRASTIC scores and subscores are more site-specific than those at the county level, they may be more accurate in capturing the degree of ground-water vulnerability associated with the sampled wells. Data used for sub-county scores included the sources used for the county-level scores, well drilling logs and information on soil and aquifer media obtained from local experts and State, county or regional sources.

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[1] See Section 2.2 of this chapter.

[2] The DRASTIC system was developed by the National Water Well Association (NWWA) for the EPA and its scoring is described in detail in Allen, L., T. Bennett, J. Lehr, R. Petty, and G. Hackett, DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings, April 1987, EPA-600/2-87-035 (hereafter, DRASTIC: A Standardized System).

The DRASTIC scoring system is based upon a series of ratings and weights. Each DRASTIC factor is assigned a weight between one and five based upon its importance relative to the other factors. Definitions of the seven DRASTIC components and their relative weights for the NPS are provided in Exhibit 2-3.[3] The weights are those generally used for Agricultural (pesticide) DRASTIC. Agricultural DRASTIC is a modification of DRASTIC that addresses the potential degradation of pesticides within soil; consequently it weights soil media and topography factors more heavily than "normal" DRASTIC.

Exhibit 2-3

Agricultural DRASTIC Subcomponent Definitions and Weights

DRASTIC Factor and Acronym		Weight	Definition
Depth to water	D	5	Depth to static water levels in unconfined aquifers; to base of aquitard in confined aquifers. Effects of artificial recharge removed. As depth increases, the score decreases.
Net Recharge	R	4	Natural recharge to water table or to confined aquifer. Effects of artificial recharge removed. As net recharge increases the score increases.
Aquifer media	A	3	Lithology and structure of aquifer; emphasis upon attenuation and hydraulic properties. More porous media have higher socres than less porous media.
Soil media	S	5	Texture of the most significant soil layer; emphasis upon attenuation and infiltration. As permeability of soil type increases, the score increases.
Topography	T	3	Degree of slope determined from large scale topographic maps or published soil surveys. As the steepness of the topography (percent slope) increases, the score decreases.
Impact of vadose zone	I	4	Lithology of unsaturated zone for unconfined aquifer or material above confined aquifer; emphasis on attenuation and hydraulic properties. Less attenuating and more porous media have higher scores.
Hydraulic Conductivity	C	2	Ease of ground-water flow as inferred from well data or from lithology. As the conductivity increases, the score increases.

The DRASTIC factors consist of continuously distributed values such as depth to water table, and sets of classes such as aquifer media. Both types of data are categorized into ranges or groups. The categories are evaluated for their relative impact on ground-water vulnerability and assigned a rating of one to ten.

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[3] Ranges and weights for Agricultural (Pesticide) DRASTIC scores are provided on pages 20 to 33 of DRASTIC: A Standardized System. Detailed descriptions of each DRASTIC factor are provided on pages 44 to 62, and those pages should be consulted for full definitions of the factors.

- Depth to water determines the depth of material through which a contaminant must travel before reaching the aquifer. Greater depths are typically associated with lower potential for ground-water contamination.

- Net Recharge of an aquifer is measured as the difference between the amount of water available to enter the aquifer (e.g., local mean annual precipitation, and local irrigation application) and the amount of water that does not reach the aquifer (e.g., potential evapotranspiration, and estimated runoff).

- For Aquifer media an increase in grain size and fractures or openings within an aquifer is associated with an increase in permeability and a decrease in attenuation capacity (sorption, reactivity, and dispersion) for contaminants.

- The Soil media is defined as the uppermost portion of the vadose zone characterized by significant biological activity (usually less than three feet in depth). Soil type is a major controlling factor of the infiltration process and contaminant attenuation through filtration, biodegradation, sorption, and volatilization. In general, the effect of soil on pollution potential depends on the clay content, the shrinking or swelling potential of the clay, the grain size of the soil, and the presence of organic material.

- The chance that a chemical remains on the land surface for subsequent infiltration is partly controlled by the Topography, measured as the percent of local slope. In general, steeper slopes signify a high run-off capacity and a lower chance of infiltration and ground-water pollution potential.

- The vadose zone is defined as the zone above the water table and below the soil horizon that is unsaturated or discontinuously saturated. When evaluating a confined aquifer the Impact of the vadose zone is expanded to include saturated zones that overlie the aquifer. The type of vadose zone media controls the attenuation of contaminants below the soil horizon and above the water table. The vadose zone media also controls the flow path and path length of contaminants. An increase in grain size or fractures and openings in the vadose zone is associated with an increase in permeability and a decrease in attenuation capacity through biodegradation, neutralization, mechanical filtration, chemical reaction, volatilization, and dispersion.

- Hydraulic Conductivity of an aquifer is associated with interconnections of void spaces within the aquifer, which facilitate rapid ground water and contaminant movement. The greater the hydraulic conductivity the greater the pollution potential. The DRASTIC scoring system reflects the close relationship between hydraulic conductivity and aquifer media.[4]

The DRASTIC weights and ratings are combined in an additive model to produce the DRASTIC index (or total DRASTIC score). In the model, the weight of each DRASTIC factor is multiplied by the selected rating for that factor, and the products summed to form the total DRASTIC score.

The second component of the DRASTIC method, hydrogeologic settings, are defined within the DRASTIC system as having common hydrogeologic characteristics and common vulnerability to ground-water contamination. Settings represent areas larger than 100 acres in size. In the United States, the DRASTIC system recognizes 111 hydrogeologic settings. The seven DRASTIC factors are evaluated for each hydrogeologic setting identified in a local area, such as within a county, to produce a more precise ground-water vulnerability index than a broad area DRASTIC score can provide.

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[4] DRASTIC: A Standardized System, p. 68.

County and sub-county areas were evaluated using available data and expert opinion and DRASTIC scores were recorded on coding sheets. The percent of each county that corresponds to each individual DRASTIC subcomponent rating was entered on the coding forms, along with the hydrogeologic settings and a variability index. Two initial methods of forming subcomponent scores were used. The first used the most likely rating for each component. The second method used a weighted average of the different responses for the component. These scores were incorporated into the DRASTIC index model to produce both a "most likely" total score and a "weighted average" total score. A variability index (related to aquifer media and vadose zone) was also included on the DRASTIC coding sheets. This was used to measure hydrogeologists' opinions on the variability that may be associated with the previously determined "weighted average" total DRASTIC score. The variability index was used to adjust the "weighted average" total DRASTIC score to produce an adjusted weighted average. Of the three total DRASTIC scores available, this DRASTIC score, termed the VARSCORE, was thought to be the most likely to reflect ground-water vulnerability.[5]

To prepare the DRASTIC scores for the Phase II analysis, data from the coding forms were entered into a computerized database. The coding forms were reviewed for inconsistencies and adjustments were made, where necessary, to remove the inconsistencies. This operation was performed separately for county level DRASTIC, used at the first stage of both the CWS and rural domestic well surveys, and sub-county DRASTIC, used at the second stage of the rural domestic well survey. Exhibit 2-4 summarizes the first and second stage DRASTIC variables included in the Phase II analysis.

Exhibit 2-4

DRASTIC Scores Used in Phase II Analyses

DRASTIC Related Score	DRASTIC Variable Name	Data Definition
Total depth to water	DEPTH	Weighted average depth index.
Net recharge	RECHARGE	Weighted average recharge index.
Aquifer Media	AQUIFER	Weighted average aquifer index. Not adjusted for index variability.
Soil Media	SOIL	Weighted average soil index.
Topography	TOPOGRAPHY	Weighted average topography index.
Impact of Vadose Zone	IMPACT	County weighted average. Not adjusted for index variability.
Hydraulic Conductivity	CONDUCTIVITY	Weighted average conductivity index.
"Weighted average" total	WGTSCORE	DRASTIC index using the weighted average DRASTIC ratings.
Adjusted "weighted average" total	VARSCORE	WGTSCORE adjusted for the variability index.

2.1.3 Land Features

Sampling teams completed on-site well observation forms for CWS wells and rural domestic wells, recording information about the topography around the well, the soil texture, land uses within 300 feet of the well, and the presence within 300 feet of the well of such features as drainage ditches, bodies of water, septic

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[5] DRASTIC: A Standardized System, pp. 75-83.

County and sub-county areas were evaluated using available data and expert opinion and DRASTIC scores were recorded on coding sheets. The percent of each county that corresponds to each individual DRASTIC subcomponent rating was entered on the coding forms, along with the hydrogeologic settings and a variability index. Two initial methods of forming subcomponent scores were used. The first used the most likely rating for each component. The second method used a weighted average of the different responses for the component. These scores were incorporated into the DRASTIC index model to produce both a "most likely" total score and a "weighted average" total score. A variability index (related to aquifer media and vadose zone) was also included on the DRASTIC coding sheets. This was used to measure hydrogeologists' opinions on the variability that may be associated with the previously determined "weighted average" total DRASTIC score. The variability index was used to adjust the "weighted average" total DRASTIC score to produce an adjusted weighted average. Of the three total DRASTIC scores available, this DRASTIC score, termed the VARSCORE, was thought to be the most likely to reflect ground-water vulnerability.[5]

To prepare the DRASTIC scores for the Phase II analysis, data from the coding forms were entered into a computerized database. The coding forms were reviewed for inconsistencies and adjustments were made, where necessary, to remove the inconsistencies. This operation was performed separately for county level DRASTIC, used at the first stage of both the CWS and rural domestic well surveys, and sub-county DRASTIC, used at the second stage of the rural domestic well survey. Exhibit 2-4 summarizes the first and second stage DRASTIC variables included in the Phase II analysis.

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Impact of Vadose Zone	IMPACT	County weighted average. Not adjusted for index variability.
Hydraulic Conductivity	CONDUCTIVITY	Weighted average conductivity index.
"Weighted average" total	WGTSCORE	DRASTIC index using the weighted average DRASTIC ratings.
Adjusted "weighted average" total	VARSCORE	WGTSCORE adjusted for the variability index.

2.1.3 Land Features

Sampling teams completed on-site well observation forms for CWS wells and rural domestic wells, recording information about the topography around the well, the soil texture, land uses within 300 feet of the well, and the presence within 300 feet of the well of such features as drainage ditches, bodies of water, septic systems, farmland, buildings, livestock waste storage pits, pesticide storage areas, and other wells. (Appendix D of the NPS Phase I Report provides the full text of questionnaires.)

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[5] DRASTIC: A Standardized System, pp. 75-83.

2.1.4 Data on Pesticides and Fertilizer Use and Agronomic Activities

Questionnaires were administered to community water system owner/operators, rural domestic well owners/residents/farmers, and county agricultural extension agents. Data were collected on farm pesticide uses, spills, and disposal practices; crops grown; animal husbandry practices; fertilizer applications; and irrigation practices on the property and within one-half mile of the well. Farming-related questionnaire items were designed to gather specific information relating to potential sources of pesticides and nitrate in well water. The types of farming data provided by the respondents are:

- Community water system owners/operators provided information on crops grown and pesticides used, including pesticide storage and disposal areas on the property.

- Rural domestic well owners or the tenants residing on the property provided information on crops grown and pesticides used; pesticide storage and disposal areas; animal husbandry practices; nitrogen fertilizer practices; and sources of irrigation water on the property.

- County extension agents provided information pertaining to the area within one-half mile of the well on crops grown and pesticides used; accidental spills of pesticides; irrigation practices; and farming management practices.

In addition to the NPS field questionnaires, three additional non-NPS databases were used to provide data on pesticide use, nitrogen fertilizer use, crops grown, and farm animals raised.

During first-stage stratification, EPA developed pesticide use estimates for each county based on information about crop acreages from the 1982 Census of Agriculture and on private marketing data on pesticides provided by Doanes Marketing Research, Inc.[6]

The second database was compiled for EPA by Resources for the Future, Inc. of Washington, D.C. (RFF) on the estimated use of 96 pesticides by crop for each of the 3,137 counties and county equivalents in the U.S. This database includes county-level estimates derived from state-level data on: (1) use estimates for 42 herbicide active ingredients primarily used on farm crops; (2) use estimates for 16 insecticide active ingredients primarily used on farm crops; (3) use estimates for 10 selected active ingredients used by urban applicators; and (4) use estimates for 10 selected active ingredients used on golf courses.[7]

The third database consists of state-level nitrogen fertilizer sales data prepared at the Division of Resources Management at West Virginia University in conjunction with the National Fertilizer and Environmental Research Center (NFERC) at the Tennessee Valley Authority in Alabama and county-level 1987 Census of Agriculture data on field animals raised and acreage of crops grown.[8]

The nitrogen fertilizer sales database consists of nitrogen fertilizer sales totals for each state. States require fertilizer dealers to report sales to state regulatory agencies. This information is submitted in the form of tonnage reports as inspection or tonnage fees are paid. The nitrogen sales data is also broken down into subgroups of nitrogen fertilizer. These subgroups are ammonium nitrate, anhydrous ammonia, miscellaneous forms, nitrogen in solution, and urea. The subgroups are mutually exclusive and exhaustive, meaning that the total nitrogen sales measured in tons is the sum of these five component parts. Annual data are currently available for the past six years (July 1, 1984 through June 30, 1990). A subset of the annual data corresponding to nitrogen sales in the fall months is also available for each nitrogen group and year. The data can be used to generate similar data for the spring season (for the nitrogen fertilizer sales data the year is considered in two parts corresponding to fall and spring).

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[6] Derivation of County-Level Pesticide Usage Estimates for Design of the Groundwater Pesticide Survey, EPA Office of Pesticide Programs, September 1985, and NPS Phase I Report, p. B-4.

[7] The data are described in Gianessi, L.P., and Puffer, C.A., November 1990, The Use of Herbicides in the United States, Resources for the Future, Inc., Washington, D.C., and Gianessi, L.P., and Puffer, C.A., January 1991, Estimation of County Pesticide Use on Golf Courses and by Urban Applicators, Resources for the Future, Inc., Washington, D.C.

[8] County-Level Fertilizer Sales Data, United States Environmental Protection Agency, Policy Planning and Evaluation (PM-221), September, 1990.

Two sets of nitrogen sales data are available for each year and nitrogen group. The first corresponds to the raw data submitted by the states to NFERC at the Tennessee Valley Authority. The second consists of estimated data using a model developed at West Virginia University. The 1987 Census of Agriculture data on fertilizer expenditures by farmers is used to develop the county estimates. The estimates are generated by allocating NFERC state totals, which are available for all states, among counties in proportion to reported expenditures on all fertilizers, as reported in the 1987 Census of Agriculture.

The second part of the NFERC/EPA database consists of county-level information gathered from the 1987 Census of Agriculture. The data are organized into three categories: general crop acreage and crop and livestock value; specific crop acreage and crop production; and animal counts.

2.1.5 Data on Non-Farming Activities Involving Pesticides

Questionnaire data were collected on non-farm pesticide uses, spills, storage, and disposal practices; household, lawn, and garden chemicals used; and land uses on the property and within one-half mile of the well. Additional questions were also administered on the age and depth of the well and well construction. The same questionnaires used in collecting the farming data were used in collecting the non-farm data. Questionnaires were administered to CWS owner/operators, rural domestic well owners/residents, and county agricultural extension agents. Questionnaire items were designed to gather information about potential sources of pesticide use, land features, and well construction practices that could affect the detection of the NPS analytes. Data provided by the respondents include:

- Community water system owners/operators provided information about the construction of the well, the well casing, including screens and grouting; the type of aquifer (confined or unconfined) from which the well draws water; other operating/non-operating wells within 500 feet of the sampled well; non-farm pesticides used or disposed of on the property; and septic systems located on the property.

- Rural domestic well owners or household tenants provided information on the construction of the well, the well casing, including screens and grouting; other operating/non-operating wells within 500 feet of the sampled well; non-farm pesticides used or disposed of on the property; septic systems located on the property, types of animals raised, and types of animal husbandry practices (feedlots, dairy, grazing) on the property.

- County extension agents provided information pertaining to the area within one-half mile of the well on bodies of water, hazardous chemical spills, non-agricultural pesticide spray applications, and facilities such as military bases, golf courses, pesticide retail outlets, and septic systems.

In addition, the RFF pesticides database also includes estimates for urban and golf course use constructed from data from 1982 national surveys conducted by EPA's Office of Pesticide Programs. The urban applicators survey included three groups of applicators; tree, lawn, and structural. Further information used to construct the golf course database came from the 1980 Census of Housing and the National Golf Foundation.

2.1.6 Data on Well Water Characteristics

Well water pH, temperature, and electrical conductivity (measured as ppm total dissolved solids) were measured during the sampling process to ensure that fresh ground water rather than water that had been standing in the well or piping was being collected. Sampling teams recorded the initial pH, temperature, and conductivity of well water, and remeasured each at five minute intervals up to a maximum elapsed time of 30 minutes. A data set consisting of the initial, stabilized,[9] and final (after the last sample bottle was filled) readings of well water temperature, pH, and conductivity was derived from the well records. The stabilized and final readings of temperature, pH, and conductivity were considered the most representative of ground water in the aquifer. The stabilized readings were used in the Phase II analysis.

2.1.7 Data on Chemical Properties of Pesticides

The fate of pesticides in soil is partially dependent on two characteristics: half-life of the pesticide in soil and soil adsorption coefficient (organic carbon partition coefficient, or K_{oc}). The half-life is used to measure the time for a chemical to dissipate and/or degrade to half its initial concentration. The K_{oc} is related to the relative mobility of the compound in soils. A database was compiled of 64 of the 127 analytes included in the NPS with their known soil half-life and K_{oc}.[10]

2.1.8 Precipitation and Drought Data

Seasonal and yearly precipitation levels may influence the leaching potential of pesticides and fertilizers applied to soil. To analyze the influence of precipitation and drought conditions, NPS collected precipitation records and data on the Palmer Drought Index scores for counties in which wells were sampled.

Precipitation. Precipitation information was retrieved from a database maintained by the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). Precipitation data were extracted from a data set called Climatedata distributed by EarthInfo, Inc. of Boulder, Colorado. Climatedata is identical to the TD-3200 Summary of the Day Cooperative Observer Network database maintained by NCDC.

NPS collected precipitation data from weather stations across the U.S., using counties as the basic unit. Data were obtained for 405 counties for community water system wells (399 counties where sampling occurred and 6 counties contiguous to counties where sampling occurred when the latter had no eligible weather station within its borders) and 90 counties for rural domestic water wells. Using station descriptions and maps from the Climatological Data Annual Summary published by NCDC, weather stations were selected based on the following two criteria:

- precipitation information is available for the station from 1980 to 1989; and
- the station is located in a county included in NPS or contiguous to such a county if that county has no eligible weather station.

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[9] Well water was defined as stabilized when: (1) two water temperatures, taken five minutes apart, were within one degree Celsius of each other; (2) two pH readings, taken five minutes apart, were within 0.2 units of each other; and (3) two conductivity readings (reported as TDS in ppm), taken five minutes apart, were within 1 ppm of each other.

[10] Values reviewed and approved by the EPA Office of Pesticide Programs were used when available for K_{oc} and half-life. Sources included values prepared in 1989 for the U.S. EPA Environmental Criteria and Assessment Office as revisions to the Superfund Public Health Evaluation Manual, 1986, and tables included in R. Don Wauchope, "Selected Values for Six Parameters from the SCS/ARS/CES Pesticide Properties Database: A Brief Description," February 20, 1991.

Once weather stations were selected, total monthly precipitation for each station was derived from available daily precipitation data using the standard NCDC method.[11] For about 50 percent of counties sampled by NPS, multiple weather stations were available for the precipitation analysis. In these cases, the derived total monthly precipitation from these stations were averaged to provide a single value for the county. A new set of variables depicting short-term and long-term precipitation characteristics, based on the sampling date (month and year), was then extracted from the monthly precipitation data set. This set of precipitation variables was used in NPS to assess the relationships between long and short term precipitation characteristics and the occurrences of pesticides and nitrate in NPS well water samples. The derived total monthly precipitation is highly generalized and may not be representative of precipitation patterns at a highly localized level such as the wellhead area.

Palmer Drought Index. Information on drought was extracted from "Drought Severity Index by Division" maps generated by the Climate Analysis Center of NOAA. The Drought Severity Index or Palmer Drought Index (PDI) was developed by Palmer in 1965 to evaluate drought. PDI is used jointly by NOAA and United States Department of Agriculture to depict prolonged abnormal dryness or wetness on a regional scale. PDI is calculated for each climatic division designated by NOAA and takes into account long-term values of evapotranspiration, recharge, runoff, and net loss of soil moisture for the specific climatic division. Because of the autoregressive nature of PDI (i.e., inclusion of past values in its formulation), PDI does not respond quickly to short-term moisture input and thus is generally not representative of short-term drought or moist spell conditions. In the NPS, data on drought and moist spells were extracted from the "Drought Severity Index by Division" maps associated with the first week of each month.

On the basis of sampled well locations and climatic division maps from the Climatological Data Annual Summary published by the National Climatic Data Center (NCDC) of NOAA, corresponding climatic divisions were obtained for all sampled wells. A data set consisting of drought severity categories for the Divisions in which wells were located was then extracted from the "Drought Severity Index by Division" maps for data analysis.

2.1.9 Data Availability

Data collected by EPA during the NPS, including chemical analysis results, QA/QC records, stratification, and questionnaire data, are available from the Office of Pesticides Programs docket. The data are in SAS files on tape for IBM mainframe use, together with a data dictionary and other documentation. For access to the data, write to: U.S. EPA, Office of Pesticides Programs Docket, H7506c, 1921 Jefferson Davis Highway, Arlington, Virginia 22202.

2.2 Statistical Approach

This section describes the procedures that were followed to analyze NPS data for this Phase II Report. Section 2.2.1 provides an introduction to the section and outlines the procedures, first listing them and then discussing the statistical software packages used to carry them out. Section 2.2.2 discusses the effective sample size and effective detection size available for the analyses and constraints that these sizes imposed on the analyses. Section 2.2.3 describes the data reduction and recoding that was carried out. Finally, Section 2.2.4 discusses each of the statistical procedures in detail.

2.2.1 Introduction and Outline of Procedures

A stratified, multistage procedure with clustering and disproportionate sampling was used to select wells for the National Pesticide Survey (the design is fully described in the Phase I Report). Consequently, procedures that account for the complex sampling design, particularly weights corresponding to the inverse probability of well selection, were used to analyze the Survey data.

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[11] NCDC computes monthly statistics if a particular month contains no more than 10 days of missing values. If this criterion is met, monthly precipitation is calculated as the sum of all daily precipitation in that month.

The Phase II analyses sought to identify associations or relationships between detections of NPS analytes in well water and ground-water vulnerability, pesticide use, farming practices, and other factors. The following procedures were used to analyze the NPS data:

- Cross tabulation and chi-square (X^2) tests for independence;
- Exploratory analysis (graphing, means, medians and quantiles);
- Univariate logistic regression;
- Univariate linear regression;
- Analysis of Variance and t-tests;
- Multivariate regression analyses; and
- Models to estimate concentration distributions.

The Phase II analysis used Taylor linearization to provide variance estimates for parameters of the statistical models.[12] These procedures properly account for complex survey designs and incorporate procedures for performing chi square tests for independence and estimating coefficients in linear and logistic regression models.[13]

Additional statistical software that was used to analyze the NPS data included a specially written maximum likelihood estimation procedure that was used to estimate parameters of a mixture model consisting of a lognormal distribution with a point mass at zero. This software was used for developing concentration distributions for nitrate and DCPA acid metabolites.

The dependent variable for the various statistical analyses reported in Chapter 3 is usually a function of chemical detections or concentrations of nitrate or pesticides in well water samples. These analyses pertain to detection of NPS chemicals above the NPS minimum reporting limits, i.e., nondetection does not imply noncontamination with certainty, it implies that the chemical is not found in the sampled water at levels above the NPS minimum reporting limits.[14] In this report, detection is generally used to mean concentration above the NPS minimum reporting limit, and occurrence is used to mean concentration above zero.

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[12] Shah, B.V., LaVange, L.M., Barnwell, B.G., Killinger, J.E., and Wheeless, S.C., SUDAAN: Professional Software for SUrvey DAta ANalysis, Research Triangle Institute, Research Triangle Park, NC, March, 1989 (hereafter SUDAAN documentation). The primary package used for analysis of NPS data was version 5.50 of SUDAAN on an IBM PC. The SUDAAN procedures are both time consuming to set up and to run, requiring the maximum memory available on a standard IBM PC (640k bytes memory available) to run the simplest programs. Consequently, exploratory analysis was generally performed using version 6.04 of the SAS statistical software package on an IBM PC. SAS/STAT User's Guide, Release 6.03 Edition, SAS Institute, Inc., SAS Circle, Cary, NC, 1988 (SAS Technical Report P-200, SAS/STAT Software: CALIS and LOGISTIC Procedures, Release 6.04, SAS Institute, Inc., SAS Circle, Cary, NC, 1990). Other analyses were performed in SAS when they did not require that the sampling weights associated with each well be included. For instance, some analyses were performed at the analyte level instead of the well level.

[13] For the analyses performed in Phase II, the Taylor linearization method has been shown to perform at least as well as other methods based on resampling approaches (such as jackknife, balanced repeated replicates, and Fay's method (Dippo, C.S., Fay, R.E., and Morganstein, D.H., Computing Variances from Complex Samples with Replicate Weights, Proceedings of the American Statistical Association, Section on Survey Research Methods, Washington, D.C., August, 1989) when estimation procedures are fairly simple, and the range of items for which variance estimates are required is fairly limited (See Judkins, D.R., Fay's Method for Variance Estimation, Journal of Official Statistics, Vol. 6, No. 3, pp. 223-239, Sweden, 1990). The Taylor linearization method requires considerable computer resources for most analyses, which limits its capacity for complex analysis. Variance estimation of loglinear models currently has not been developed for the SUDAAN package, which limits the scope of categorical data analysis to chi square tests for independence and logistic regression models. Taylor linearization also cannot be used to provide reliable variance estimates for nonlinear parameters, such as medians.

2.2.2 Samples Used for Analysis

Nitrate was the only chemical detected with sufficient frequency in the NPS that the statistical analysis could be performed without great concern that the statistical assumptions required to perform the analyses might not be satisfied. Analysis of NPS data was carried out using the following groups of chemicals:

- Nitrate;
- Any pesticide;
- DCPA acid metabolites;
- Atrazine;
- Triazines; and
- Herbicides.

Analytical results for the groups that contain more than one chemical pertain to all NPS analytes that fall into those groups. For example, the triazine group consists of ametryn, atrazine, deethylated atrazine, cyanazine, hexazinone, metribuzin, prometon, prometryn, propazine, simazine, and terbutryn. However, the analysis focused on those chemicals within a group that were detected. For the triazine group, these are atrazine, prometon, and simazine only (in both the CWS and rural domestic well surveys). For the herbicide group, chemicals that were detected are:

- CWS wells: atrazine, dinoseb, DCPA acid metabolites, prometon, and simazine.
- Rural domestic wells: alachlor, atrazine, bentazon, DCPA acid metabolites, prometon, and simazine.

Although analysis using the "any pesticide" group centers on those pesticides or pesticide degradates that were detected, the analysis pertains to all NPS pesticides and pesticide degradates and not just to the detected analytes. That is, the hypotheses being investigated for the groups of analytes pertain, respectively, to all NPS triazines, all NPS herbicides, and all NPS pesticides and pesticide degradates, and not only to the detected analytes in each of these groups.

Chi-square tests for independence and logistic regression modeling were performed using detections of pesticides or nitrate as the dependent variable. (All analyte groups listed above were analyzed but the only two groups that provided acceptable results were any pesticide and nitrate.) Although the chi-square procedures have no dependent variable per se, the independence hypothesis concerned detections of a pesticide or nitrate and a categorical (usually binary) response variable that could possibly explain detections. The descriptive significance level resulting from a 2X2 chi-square analysis is identical to the value obtained using univariate logistic regression with categorical variables. Detections thus may be thought of as the dependent variable in the chi-square tests of independence. However, no regression coefficient indicating the amount of influence of the independent variable on the dependent variable is produced by the X^2 test.

Linear regression models were used to analyze nitrate concentrations. A logarithmic transformation of the nitrate concentrations was necessary for all linear regression models where nitrate concentrations are the dependent variable. For all regression models presented in Chapter 3 the results are valid only for within the range of the data. When nitrate concentrations are the dependent variable the range of the data is from 0.15 mg/L (i.e., the minimum reporting limit for nitrate in the NPS) to the highest detected concentration.

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[14] Tables of the NPS minimum reporting limits can be found in the NPS Phase I Report, Appendix E.

The corresponding regression models may not be appropriate outside this range. The linear regression models involving nitrate concentrations are also conditional on detection above 0.15 mg/L. That is, the wells that did not contain nitrate at or above detectable levels are not included in these analyses. Analysis of nitrate occurrence in CWS and rural domestic wells often began by identifying a relationship with nitrate detections through logistic regression. If a relationship was found, a linear regression model then was used to determine if a similar relationship could be found with nitrate concentrations above 0.15 mg/L.

Whenever data were logarithmically transformed, normal probability plots were prepared for the transformed data, and in each case normality was verified.

2.2.2.1 Effective Sample Size

The primary goal of the NPS, carried out in Phase I, was to assess the proportion of CWS and rural domestic wells nationally that contain pesticides or pesticide degradates. In Phase II, chi-square tests for independence, logistic regression, and linear regression were used to analyze relationships between pesticide or nitrate detections and factors that may affect detection, such as well characteristics, pesticide use, ground-water vulnerability, location, characteristics within the vicinity of the well, and precipitation. These statistical methods are more complex than methods for estimating simple proportions and their standard errors such as those in the Phase I analysis. The NPS Data Quality Objectives (DQOs), which established the precision requirements for sampling water supply wells led to the sample allocation for the Survey. The DQOs were adequately satisfied for Phase I of the Survey, principally because the number of pesticide detections realized was far greater than had been anticipated.[15] During the design of the study, EPA decided to accept the sample sizes set by the DQOs for Phase I. Because the sample sizes were set to meet sample sizes for Phase I, no explicit DQO's for Phase II were established. Given the time and cost constraints, the 1985 Scientific Advisory Panel concurred, noting that it would be difficult to increase the sample sizes by a significant enough number to affect the confidence of the interpretations. EPA therefore maintained the sample size chosen for Phase I.[16] In general, the Phase II analyses require larger sample sizes than Phase I analyses.

Appendix B of the Phase I Report discusses the effective sample size for the CWS and rural domestic well surveys. The effective sample size is the sample size which would be required to achieve the same level of precision in the analyses if a simple random sample had been taken (given that the proportions of pesticide detections remain constant). The ratio of the actual sample size to the effective sample size is termed the design effect. In the NPS, the design effect measures the extent to which stratification, clustering, and disproportionate sampling cause the information contained in the NPS sample to differ from the information provided in a simple random sample. The design effects for the CWS and rural domestic well surveys were approximately 1.27 and 1.84, leading to effective sample sizes of 426 and 410 respectively. That is, the CWS and rural domestic well samples contain the equivalent information of simple random samples with 426 and 410 sampled wells. These effective sample sizes achieved by the NPS were not always capable of achieving the necessary number of observations for the Phase II analyses. A guideline for adequacy of the chi-square test for independence procedures is that the equivalent information of at least five observations must be expected in each cell of the cross tabulations to satisfy the test's assumptions. This guideline is used to meet requirements of the chi-square approximation to the hypergeometric distribution (or normal approximation to the binomial distribution) that underlies the testing procedure.

2.2.2.2 Effective Detection Size

Effective detection size is related to effective sample size. That is, the effective sample consists of pesticide detections and non-detections. The proportion of rural domestic wells with pesticide detections is

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[15] Black, P.K., Johnson, L., and Lester, H., National Pesticide Survey Data Quality Objectives: Evaluation and Results, Proceedings of the Fourth Annual Ecological Quality Assurance Workshop, Cincinnati, Ohio, February 1991.

[16] NPS Phase I Report: Appendix A, p. A-11.

4.2% (see the Phase I Report). This corresponds to an effective detection size of 17 (to the nearest integer). Effective detection sizes for the full design for the chemical groups analyzed are provided in Exhibit 2-5.

Exhibit 2-5

Effective Detection Sizes for Groups of Chemicals in the NPS Community Water System and Rural Domestic Well Surveys

Chemical Group	Estimated National Proportion of Wells With Detections	Effective Detection Size
CWS:		
Nitrate	51.9%	220.6
Any Pesticide	10.4%	44.3
Herbicides	9.5%	40.5
DCPA acid metabolites	6.4%	27.0
Triazines	3.2%	13.4
Atrazine	1.7%	7.0
Rural Domestic:		
Nitrate	56.9%	232.8
Any Pesticide	4.2%	17.4
Herbicides	3.6%	14.9
DCPA acid metabolites	2.5%	10.3
Triazines	1.1%	4.4
Atrazine	0.7%	2.7

As Exhibit 2-5 demonstrates, a sufficient number of effective detections to satisfy the assumptions or guidelines required for the statistical analyses was achieved for only a few groups of analytes. These groups, for the CWS well survey, are nitrate, any pesticide, herbicides, and sometimes DCPA acid metabolites; for the rural domestic well survey they are nitrate, and perhaps any pesticide. Detected chemicals in the any pesticide group consist mainly of herbicides, and detected chemicals in the herbicides group consist mainly of DCPA acid metabolites and atrazine. Statistical analyses for any pesticide are likely to produce more powerful results than those for herbicides, and the direction of any effect is likely to be the same. Consequently, most results for pesticides are for any pesticide rather than for a smaller group of pesticides. There are sufficient nitrate detections for reasonable analysis of nitrate detections and nitrate concentrations above 0.15 mg/L.

To the extent that data are missing in a particular chemical group, the effective detection sizes available for analysis are smaller than those given. This occurred, however, in very few cases. Assuming the relative proportions in a cross tabulation remain constant, then as the sample size for a chi-square test of independence decreases, the potential for realizing an expected value of at least five observations in each cell also decreases.

2.2.2.3 Statistical Quality Control and Interpretation

For analyses reported in the succeeding chapters the sample sizes have been judged to be sufficient to satisfy statistical assumptions and to adequately control the chance of not rejecting hypotheses when, in fact, they should be rejected. Analysts not familiar with using survey data from complex sample designs should note that in order to satisfy the statistical criteria for specific procedures they must incorporate the survey design, including selection probabilities, to correctly estimate standard errors and descriptive significance levels (p-values). As discussed in Sections 2.2.2 and 2.2.3 effective sample and detection sizes were calculated based on the Survey design for all analyte groups and questionnaire items used in the analyses. The effective sample sizes and effective detection sizes were used in NPS as an efficient screening criteria to judge analyses with respect to statistical assumptions and Type II error concerns. Analyses reported in the succeeding chapters are judged to adequately satisfy the statistical assumptions for X^2, logistic regression, and linear regression procedures. In addition, each result has been judged to adequately control for Type II error (i.e., the probability of not rejecting the hypothesis when it should, in fact, be rejected) or, equivalently, the power of the test result (i.e., the probability of rejecting the hypothesis when it should be rejected).

The power of each test is related to the amount of information contained in the data. For example, analyses of NPS data are measured by the effective sample size and the effective detection size (or effective number of observations in categories under investigation). Two distinct analyses may yield equal p-values indicating significance of a hypothesis, but one result may be stronger than the other because of the amount of information contained in the data. The relative importance of each analysis may be measured by the power of the test, but in practice the power is often very difficult to calculate. Consequently, guidelines for adequacy of the procedures are often used to control for the effect of power. For example, for X^2 tests for independence of attributes an expected value of at least five observations per category is often required.

Exhibit 2-5 shows the effective detection sizes for specific analyte groups. It is important to understand that effective sample sizes will vary with each specific test that is conducted. This occurs in the NPS for two closely related reasons. First, the amount of missing data for each analysis varies. Missing data is most often a result of "don't know" responses to questionnaire items and incomplete national data from external databases. Second, effective sample sizes are smaller for response to questionnaire items that are asked only when a prior question has a specific response (i.e., due to a skip pattern). Although the effective sample and detection sizes may vary for each analysis, results are presented in Chapters 3 and 4 only when Type II error is judged to be adequately controlled and statistical assumptions have been adequately satisfied.

The following examples help to illustrate the points raised in this section:

> CWS Local Area Questionnaire items 12e (pertaining to the presence of a lined drainage ditch within one half mile of the sampled well) and 14b (pertaining to use of flood irrigation within one half mile of the sampled well) were analyzed for associations with nitrate detections. Both X^2 analyses yielded p-values of 0.019. However, the result for item 12e is stronger than the result for item 14b because the effective sample sizes for these two analyses differ dramatically. The effective sample size for the drainage ditch analysis is approximately 369 and for the flood irrigation analysis is approximately 99. Answers to the flood irrigation question occur as the result of a skip pattern and are obtained only if the respondents use irrigation. Although both analyses satisfy the statistical assumptions required for the testing procedure, the power of the test for the drainage ditch item is greater than the power of the test for the flood irrigation item.
>
> The rural domestic well Local Area Questionnaire item 11j pertaining to the presence of golf courses within one half mile of the sampled well was analyzed for an association with "any pesticide." A X^2 analysis of the test of independence of the two attributes (pesticide detection and presence of golf course) revealed a p-value of 0.002, however, the expected number of effective observations in the category corresponding to detection and presence of golf course was less than 1. Consequently, the statistical assumptions for the test are not satisfied and the test has low power.

2.2.3 Data Reduction and Recoding

At the beginning of the Phase II analysis, data reduction and recoding were performed to set up datasets that could be more easily manipulated for different series of analyses and that were more appropriate for some hypotheses of interest. Responses of "Don't know" to questionnaire items were excluded from the analyses. (EPA also analyzed the "don't know" responses as a separate category. See footnote 17 in this section.) Responses of "Other" to questionnaire items, where respondents specified a text response, were appropriately categorized. Some questionnaire items were combined because those questions were highly related, and some items were recoded to test an associated hypothesis of interest. Finally, external databases were used to create variables that were relevant to some of the hypotheses tested.

Imputation procedures were performed for missing questionnaire and analyte data in Phase I to produce national population estimates. These imputed values have been included in the Phase II analysis for consistency with the Phase I results. In addition, many of the questionnaire items contain "Don't know" as possible responses. "Don't know" responses were excluded from Phase II analyses. Imputation for these responses was not performed. Imputing values for the "Don't know" responses would require an assumption that the "Don't know" responses were random with respect to the population distribution. While this assumption is hard to justify for the "Don't know" responses, which are legitimate responses, they generally account for only a small percentage of responses and are therefore unlikely to affect the findings. Imputation for "Don't know" responses would also increase the sample size available for many of the statistical procedures, resulting in an artificial increase in statistical power. The potential for introducing bias due to any non-random effects could result in substantiation of hypotheses purely on the basis of "Don't know" responses.[17] For the reported findings with the highest "Don't Know" rates, a sensitivity analysis indicated the results were not affected.

Data from the external databases, such as the RFF pesticides database, the NFERC nitrogen database, precipitation data, and drought data, were county-specific rather than well specific. Analysis of these data was performed by first associating wells with their counties of origin, and then matching the counties with county level information from the external data. In general this leads to averaging of these data. For example, the nitrogen database contains information on crops grown and animals raised in each county. The fact that, according to that database, crops are grown in a county in which an NPS sampled well is located does not mean that the particular well is located close to cropland. Cropping values are averaged across the county to be able to associate cropping data with wells, but the averaging that this causes could affect conclusions resulting from their analysis. In addition, the RFF pesticide and NFERC nitrogen databases contain data at the county level that are prorated from the state or EPA Regional level. This proration also leads to averaging that can affect the quality of the conclusions reached from the analysis.

2.2.4 Description of Procedures

NPS data consisted of both categorical and continuous responses. Section 2.2.4.1 describes the procedures used for analyses involving categorical data; Sections 2.2.4.2 through 2.2.4.6 describe the procedures that also include continuous data.

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[17] An alternative approach to the "Don't know" responses is to include them as a separate category in the statistical analysis. Generally, there are too few of these responses to particular questionnaire items to warrant inclusion in this way. One problem with including "Don't know" responses as a separate category for analysis is that the small number of pesticide detections already available for analysis are spread even more thinly, resulting in violation of the statistical assumptions. When there were sufficient "Don't know" responses so that conclusions could be affected, further analysis was performed to verify that the initial conclusions were appropriate.

2.2.4.1 Analysis of Categorical Data: Cross Tabulation and Chi-Square Tests for Independence

Much of the NPS data consist of categorical responses, including detections of pesticides and nitrate, many questionnaire items, stratification variables, seasonal categories, and Palmer Drought Indices. Potential associations between detections of pesticides or nitrate and other categorical data were examined by performing chi-square tests for independence for two dimensional contingency tables.

Although univariate logistic regression models for categorical independent and dependent variables produce the same numerical results as chi-square tests for independence, the hypotheses may be interpreted differently. Regression models are often used to measure predictive or causal relationships. Chi-square results can be regarded as providing information on the independence or association of variables. Loglinear modeling, a generalization of both chi-square analysis and logistic regression modeling for categorical data, is not generally available in SUDAAN. However, the chi-square test statistics used in the NPS analysis are based on log odds ratios and are equivalent to a test for no interaction in the loglinear model fitted to the logarithm of the estimated cell proportions[18].

Prior to performing the chi-square tests, cross tabulations of the data were examined to verify that the tests were appropriate. Most of the data were binary, comprised of positive or negative responses to the questionnaire items. For these data the main concern was adequate satisfaction of the statistical assumptions for the testing procedure. For 2x2 tables the cross-tabulations were reviewed to indicate the direction of potential associations, i.e., whether chemical detections are positively or negatively associated with the second variable. For larger tables the cross-tabulations were reviewed to determine differences between categories.

The small number of effective detections for the pesticide groups requires a fairly even distribution across the second variable for reasonable chi-square analysis. Often, however, the responses to the questionnaire items also were unbalanced. For example, the effective number of pesticide detections in rural domestic wells is 17 for the full survey (corresponding to 4.2 percent of rural domestic wells). To achieve an expected number of observations of at least five in each cell of the contingency table requires an average of at least 220 questionnaire responses in each response category (corresponding to approximately 121 effective responses) of which 4.2 percent are detections. Furthermore, if the number of responses is not substantially more than 220 in the category corresponding to the smallest number of detections, a significant difference cannot be found. In summary, both a reasonable overall balance is required in the questionnaire responses to satisfy the statistical assumptions and a reasonable imbalance in the questionnaire responses is required to provide a significant result. The specifics of the requirement are different for each survey and pesticide group, but the requirements are satisfied for very few of the questionnaire items examined. Some of the questionnaire responses are so unbalanced that analysis of nitrate detections is not possible.

The guideline of five expected observations per cell is a conservative criterion, particularly in large contingency tables. With respect to pesticide detections, however, the expected number in a particular cell was often less than one for questionnaire items. Several approaches were taken to alleviate the problem. First, if the item in question provided binary responses (e.g., positive and negative, "yes" and "no"), similar questionnaire items were found and these items were combined using a logical "or" operation on the positive responses, and a logical "and" operation on the negative responses, to produce a new variable.

Second, when the allowable responses of the questionnaire variable were not binary, but allowed categorical responses with more than two possibilities, some of the groups were collapsed to form new groups. Collapsing of the cells of the contingency tables was based on commonalities in the responses and the need to satisfy the statistical assumptions as fully as possible. The procedure of collapsing cells has several disadvantages: some information may be lost, the unbiased nature of the sample may be affected because this procedure is performed *post hoc*, and the manner in which the categories are pooled can affect the conclusions that may be drawn. However, collapsing cells is often the best alternative for addressing the problem of insufficient data.

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[18] SUDAAN Professional Software for SUrvey DAta ANalysis, documentation, Research Triangle Institute.

Third, for large contingency tables, all 2x2 subtables can be analyzed. Generally, in this approach an adjustment to the chi-square statistic may be carried out to reflect the number of tests being performed on the same data. Brunden (1972)[19] provides an adjustment for chi-square analysis for 2x*c* contingency tables:

$$\alpha^* = \frac{\alpha}{2(c-1)}$$

A similar adjustment is made for larger contingency tables from which several chi-square analyses have been performed. For example, such an adjustment was necessary for analysis of temporal variables, which were regrouped into 3x2 and 4x2 contingency tables.[20]

Finally, in cases when the assumptions for chi-square analysis of 2x2 tables are not satisfied, EPA assessed the degree of assumption violation together with the supplied p-value to determine the appropriateness of the conclusion.

Significance levels, or p-values, represent the degree to which the hypotheses are judged to be supported by the data. The lower the p-value the more evidence there is in favor of an association between the variables' attributes, e.g., detections and questionnaire items. Statistical tests are usually performed with respect to a specified significance level (α-level) to determine whether a null hypothesis (in this case independence of attributes) should be rejected or not. For chi-square tests of independence rejection of the null hypothesis (of independence) implies that there is evidence of an association. Significance levels of 0.05 and 0.01 are most often used to determine statistical significance.

Rejection of a hypothesis at the 0.05 significance level also corresponds to a one in twenty chance of rejecting the null hypothesis of independence when it should not be rejected. That is, a one in twenty chance of producing a false positive result is accepted by specifying a significance level of 0.05. For every 1,000 tests performed, 50 can be expected, by random chance alone, to provide significant results at the 0.05 level of significance. The chi-square test for 2x2 tables is a two-tailed test (in the sense that a significant effect can be found in one of two directions corresponding to positive and negative coefficients in the equivalent logistic regression model). The NPS scientific hypotheses were often intended to be unidirectional only (for instance, pesticide use was anticipated to be associated with more pesticide detections). The implication is that for every 1,000 tests performed, 25 can be expected to yield a statistically significant result in the direction of accepted scientific hypotheses and 25 can be expected to be in the opposite direction by random chance alone at the 0.05 significance level. Although the number of statistical tests performed in the NPS has not been counted, it is likely that it greatly exceeded 1,000. The cutoff of $p \leq 0.05$ was used to determine which results were deemed to be statistically significant. A sizeable proportion of these results had p-values much less than

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[19] Brunden, M.N., The Analysis of Non-Independent 2x2 Tables Using Rank Sums, (Biometrics, Vol. 28, 1972, pp. 603-607, reprinted in Everitt, B.S., The Analysis of Contingency Tables: Monographs on Applied Probability and Statistics, Chapman and Hall, London, 1977.

[20] EPA also considered dealing with small expected cell frequencies through use of Fisher's exact test. This procedure uses the exact hypergeometric distribution to determine the probability of obtaining a result at least as extreme as that provided by the data. Fisher's exact test requires counts for input, e.g., numbers of detections and non-detections, or numbers of positive or negative responses. This appears to correspond exactly to NPS data. However, there are several obstacles to using Fisher's exact test in the NPS. In particular, there is no recognized direct method for employing the survey weights or design in the Fisher test calculations. For this reason Fisher's exact test is not available in SUDAAN. Fisher's test can be performed on the unweighted raw data, or a method for using the weights and the design must be created and implemented. The usual effect of Fisher's exact test on the descriptive significance level (p-value) is to provide more conservative results (higher p-values).

0.05. This directly reduces the overall expected rate of associations deemed to be significant due to chance to below 50 per 1,000 tests. Comparatively few results are statistically significant in the sense used here. Furthermore, nearly as many are in the opposite direction to the scientific hypothesis as are in the expected direction. Consequently, apparently significant results should be regarded with some caution. Results that are substantiated by analysis of similar variables provide the most likely indicators of pesticide or nitrate detections. To the extent that the hypotheses tested reflect a summary of data available before completion of NPS, the results that support the hypotheses are stronger than those that contradict the tested hypotheses, even when the p-values are equal.

Another concern for significance testing is that the p-value is inversely related to the amount of data. For example, under simple random sampling for a test of the difference between two means, and assuming normality is invoked, the p-value is inversely related to the square root of the sample size. There are at least two ways to interpret this: As the sample size increases to infinity the p-value decreases to zero irrespective of the actual difference between means; or as the sample size increases the power to detect differences also increases. When comparing two tests with unequal but relatively small sample sizes, the "power" argument is probably more persuasive, since the p-value is probably not being forced to zero by a large sample size. However, when both tests have relatively large sample sizes, the p-value could become small, implying a significant difference, purely because of this inverse relationship. In general it is possible to select a sample allocation that will guarantee a significant result given a difference in sample means, and the larger the sample size the more likely that significant results are to occur. Although the NPS does not contain analyses of such simple differences between sample means, the arguments are analogous. Essentially, the amount of information (data) contained in the sample is inversely related to the p-value for analyses that use that data. That is, as the amount of data increases the chance of obtaining a statistically significant result increases and the potential for false negative results also increases. Because of the relatively large number of nitrate detections, it is not surprising that most of the analyses that produce low p-values are for nitrate detections rather than pesticide detections. Thus, two trends of equal statistical significance (which always would have equal p-values) could have different strengths of association, depending on the amount of information (the number of data points and the number of detections) included in the estimate.

A significance level, or p-value, cut-off of 0.05 was used to determine inclusion of an analysis in Chapters 3 and 4, with results from 0.05 to 0.1 presented in Appendix A of this report. Such a broad range of results was presented to allow reviewers to determine for themselves which results are important. A higher cut-off would have allowed inclusion of many results of questionable significance.

Much of the discussion regarding p-values in this section also applies to the univariate logistic regression, univariate linear regression, multivariate regression, and analysis of variance procedures discussed in the following sections. These sections are used primarily to describe the further capabilities of the corresponding analyses.

2.2.4.2 Exploratory Data Analysis for Continuous NPS Variables

Continuous variables available for analysis in NPS include nitrate concentrations, minimum reporting limits, well depth and age of well from the questionnaires, DRASTIC factors, well conductivity, well water pH and temperature, estimates of pesticide and nitrogen sales, K_{oc}, half-life, and precipitation. For most analyses involving continuous variables, the dependent variable is a function of pesticide or nitrate detections for logistic regression models, and nitrate concentrations for linear regression models. The remaining data are used as independent variables. For both types of regression, analysis of the residuals is often used to provide indications for transformations of variables, identification of outliers, and model validation. Exploratory analyses were used prior to regression modeling to provide initial insights into problems that could arise. Exploratory analyses also were used to provide summary statistics and relevant plots of the data. Means, standard errors, order statistics, stem and leaf plots, box plots, and normal probability plots were examined for most continuous variables prior to inclusion of these variables in regression analysis.

2.2.4.3 Univariate Logistic Regression Modeling

Relationships between pesticide or nitrate detections and continuous NPS variables were examined using univariate logistic regression models. Logistic regression models are models for the probability of occurrence of a specified event, in this case pesticide or nitrate detections. The univariate logistic regression model for the probability of detection in the NPS can be expressed as:

$$\ln\left(\frac{Pr\ (detection)}{1 - Pr\ (detection)}\right) = \alpha + \beta X$$

The left side of the equation is the logistic or logit transformation of the probability of detections, and the variable X represents the independent factor being investigated. The predictive capability of the independent factor with respect to the probability of detection is determined through the descriptive significance level (p-value) of the β coefficient. The lower the p-value the more evidence there is to suggest that the independent variable is a good predictor of the probability of detection. The intercept term is not analyzed for statistical significance.

The logistic regression analyses were performed in SUDAAN in order to account for the survey design and the survey weights when estimating the standard errors of the ß coefficients. Residual analysis was used to identify outliers. When obvious outliers were identified, the logistic procedure was repeated on the reduced data set. If removal of the outliers did not result in substantially different results the model for the full data is presented. Transformations of the continuous independent variable used in the univariate models sometimes were performed for consistency with use of that variable in the linear regression procedures. Typically, logarithmic transformations were used. SUDAAN does not currently provide useful goodness-of-fit statistics for logistic regression models. Consequently, it is difficult to determine if transforming an independent variable provides a better model. As transformations of the independent variable do not alter the variability or shape of the error distribution it is unlikely that the logarithmic transformations of independent variables result in substantially improved models.

A further rationale for transforming the independent variable can be found by considering t-tests for detections. Logistic regression models have been developed to analyze the NPS data because the assumed model is that detections are caused by other factors. To the extent that detections and other factors are related without implied causality from factors to detections, t-tests provide a potential alternative analysis. Once the continuous variables are cast as the dependent variable the need for transformations to control variance is apparent.

Results of univariate logistic regression analyses that are presented in Chapter 3 are provided in terms of estimates of the intercept term, the β coefficient, the standard error of the β coefficient, and the p-value associated with the β coefficient, whenever the units of the independent variable can be reasonably interpreted. Many of the univariate logistic regression analyses use categorical data for the independent variable (i.e., chi-square analysis), or have transformed continuous independent variables. In both cases, if the magnitude of the ß coefficients cannot be interpreted naturally it has not been provided. For these logistic regression models the direction of the implied effect is reported instead of the β coefficient.

2.2.4.4 Univariate Linear Regression Modeling

Relationships between nitrate concentrations and continuous variables were examined using univariate linear regression models. The univariate linear regression model for nitrate concentration can be expressed as:

$$\ln\ (Nitrate\ Concentrations) = \alpha + \beta X$$

The function of nitrate concentration most often employed involves a logarithmic transformation of the data. The variable *X* represents the independent factor being investigated. The predictive capability of the independent variable with respect to the nitrate concentrations is determined through the descriptive significance level (p-value) of the ß coefficient. The lower the p-value the more evidence there is to suggest that the independent variable is a good predictor of nitrate concentrations. The intercept term is not analyzed for statistical significance.

The linear regression model for nitrate concentrations may be regarded as a conditional analysis, because only wells that recorded detections are included in the analysis. That is, the analysis is conditional on detection of nitrate above the minimum reporting limit of 0.15 mg/L.

The linear regression analyses were performed in SUDAAN to account for the survey design and the survey weights for estimating the standard errors of the ß coefficients. Residual analysis was used to identify outliers, and to verify the need for transforming the nitrate concentration data. When obvious outliers were identified the linear regression procedure was repeated on the reduced data set. If removal of the outliers did not result in substantially different results, the model for the full data is presented. Transformations of the continuous independent variable used in the univariate models were based primarily on exploratory analysis. An advantage of performing a logarithmic transformation on the independent variable as well as the dependent variable is that it allows the intercept term to be interpreted as the percent change in nitrate concentrations per one percent change in the independent variable. However, transformations of the independent variable do not affect the variability or shape of the error distribution, and are unlikely to substantially alter qualitative results.

The only goodness-of-fit statistic provided in SUDAAN for linear regression models is an R^2 statistic. This statistic is often used for comparison of nested models rather than to assess adequacy of univariate models. However, R^2 for a univariate linear regression model corresponds to the square of the correlation between the dependent and independent variables. Consequently, it can be used to help determine the adequacy of the models, and may provide an indication of the effect of transforming the variables.

Results of univariate linear regression analyses that are presented in Chapter 3 provide estimates of the intercept term, the ß coefficient, the standard error of the ß coefficient, and the p-value associated with the ß coefficient, whenever the units of the independent variable can be reasonably interpreted. Some of the univariate linear regression analyses use transformed variables. In these cases, if the magnitude of the ß coefficients cannot be interpreted naturally, it is not provided, but the direction of the implied effect is reported instead.

2.2.4.5 Analysis of Variance and T-Tests

A limited number of analysis of variance and t-tests were performed in the analysis of the NPS data. Analysis of variance (ANOVA) was performed in SUDAAN to examine the relationship between nitrate concentrations and Palmer Drought Index data; unweighted t-tests were performed in SAS to examine the relationship between K_{oc} or half-life and chemical detections in the NPS.

The formal regression model underlying ANOVA or t-tests procedures at the well level specifies nitrate concentrations as the dependent variable and indicators of Palmer Drought Index as the independent variables. At the chemical level, K_{oc} and half-life were, separately, specified as the dependent variable.

Results of the ANOVA and t-test analyses are presented in terms of an overall F-test for the hypothesis of no difference between the means of the groups. Means and standard errors are also provided.

2.2.4.6 Multivariate Analyses

Multivariate logistic regression modeling was performed for detections of pesticides and nitrate, and multivariate linear regression modeling was performed for nitrate concentrations. The procedures do not differ substantially from those presented in Sections 2.2.4.3 and 2.2.4.4. The purpose of the multivariate analyses was to examine how dependent variables were affected by a combination of independent variables.

Once the univariate analyses described in the previous sections were completed, a list of potential variables was established for use in multivariate analyses. The best regression models were determined primarily by examining correlation tables and through manual forward and backward elimination of variables. The SUDAAN procedure does not provide a procedure for stepwise regression so the p-values and R^2 statistics were examined along with the correlation tables to determine which independent variables constitute the best models.

Two categories of models were used. In both, the terms ß and X denote vectors that represent the multiple independent variables. The first category contains logistic regression models with the "log-odds" of detection as the dependent variable:

$$\ln\left(\frac{Pr(Detection)}{1 - Pr(Detection)}\right) = \alpha + \beta X$$

The second category of models, for nitrate concentrations, are linear regression models with the natural logarithm of nitrate concentrations as the dependent variable:

$$\ln\,(Nitrate\ Concentration) = \alpha + \beta X$$

These models apply only to the NPS and may be invalid outside the range of the data. This concern is particularly important for the nitrate concentration analyses, where the data are limited to concentration values above the MRL of 0.15 mg/L. Other caveats regarding measurement error in the data should also be considered.

Independent variables may be categorical or continuous. For categorical (binary) variables the corresponding columns of the design matrix consist of indicators (zero or one). The model is fit to the data using the SUDAAN package. A maximum likelihood approach is used for estimation in this procedure. There are no statistics readily available from the SUDAAN output for logistic regression that can be used for diagnostic checks of the estimated model. Because automatic stepwise procedures are not available in SUDAAN the selected model was chosen based on a manual stepwise approach that consisted of backward elimination based on t-statistics or p-values of the β-coefficient for variables that were considered.[21] This backward elimination step was followed by repeated forward and backward elimination using the variables that were eliminated in the initial manual backward elimination phase. The main criterion used for inclusion or exclusion from the model was the p-value of the β-coefficients themselves. Correlations among the model variables and the p-value of the overall model also were considered for model selection.

2.2.4.7 Concentration Distributions

This section describes the general procedures used for estimating concentration distributions for nitrate and DCPA acid metabolites in both rural domestic and CWS wells. Results of the concentration distribution analysis are presented in Section 4.4.2 of this report.

Pollutants generally occur predominately at low concentrations with relatively few occurrences at high concentrations. The lognormal distribution is often used to model such data. The NPS concentration distributions are assumed to follow a mixture model that further accounts for the possibility that some wells contain no contaminants. The model includes a component estimating the probability of non-occurrence, and a component measuring concentrations given occurrence. The former component is represented by a binomial probability (i.e., contaminants either occur or do not occur in wells), whereas a lognormal model is used to characterize the latter component. Consequently, the mixture model consists of three parameters:

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[21] Using p-values is equivalent to using t-statistics for this process because the variables used in the multivariate analysis have 1 degree of freedom (except for the Palmer Drought Index which has 2 degrees of freedom).

π The probability of non-occurrence;

μ The mean of the ℓn(concentrations) given occurrence; and

σ The standard deviation of the ℓn(concentrations) given occurrence.

Given occurrence, the natural logarithm of concentrations, denoted ℓn(concentrations), follows a normal distribution with mean μ, and standard deviation σ, if the concentrations are lognormal(μ,σ). The model also can be presented in terms of its cumulative distribution function, F($\cdot$), as follows:

$$F(x|\pi,\mu,\sigma) = \pi + (1-\pi)\, G(x|\mu,\sigma)$$

The function G($\cdot$) is the cumulative distribution of the lognormal component. Maximum likelihood estimation procedures were used to estimate the parameters of the model for nitrate and DCPA acid metabolites. Although commercial statistical software packages include maximum likelihood estimation procedures, none of these packages include a procedure that can perform maximum likelihood estimation for the types of mixture models used here and where minimum reporting limits are used. No methods or software currently exist for estimating concentration distributions using binomial/lognormal mixture models and censored data from complex sample surveys. A maximum likelihood estimation program was developed specifically to estimate distributions using censored data. This program does not account for complex survey designs or survey weights.[22]

A modified bootstrapping technique was used to produce weighted concentration distributions based on the binomial/lognormal model.[23] Monte Carlo simulation of the empirical population distribution was used to generate 40 samples of size equal to the effective sample size. Survey weights are accounted for by re-sampling from the empirical distribution and the effective sample size is used to appropriately control the variance. Estimates of relevant parameters of the concentration distributions, including π, μ, and σ, were calculated for each of the 40 random re-samples using the maximum likelihood procedure. The median of the 40 values of π, μ, and σ were produced as estimates of the concentration distribution parameters. Other parameters such as quantiles and means were similarly estimated using the median of the 40 values resulting from the maximum likelihood estimation of the re-samples.

Confidence intervals were also calculated from the results of the maximum likelihood estimation of the 40 re-samples. The 2.5 and 97.5 quantiles of the 40 re-sample estimates were used to estimate the 95% confidence intervals. An alternative approach to using the median and quantiles as estimates of parameters and confidence intervals is to use the mean and the standard error under an assumption that the 40 re-sample estimates follow a normal distribution. This assumption does not hold for many of the parameters of interest, therefore the approach using medians and quantiles was used. When the normality assumption is reasonably satisfied the results should not be very different.

Although the basic procedure used to estimate concentration distributions is similar to a traditional bootstrap procedure, it differs in some important aspects. Re-sampling in the traditional bootstrap is performed with replacement and with equal probabilities on each data point, whereas, for this exercise, re-sampling is performed with probabilities proportional to the inverse of the survey weights, though still with replacement. Also, traditional bootstrap methods create re-samples of size equal to the sample size, whereas re-samples are of size equal to the effective sample size here. The effective sample size is used to try to provide appropriate control over the variance estimates. These modifications to the traditional bootstrap seem reasonable to the extent that this approach accurately reflects re-sampling from the nonparametric maximum likelihood estimate of the empirical population distribution and the variance components are appropriately controlled, but more work is required to verify the statistical properties of this method.

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[22] An alternative to such techniques is reporting of all data, including data below the MRL and, when there are data confirmed by mass spectroscopy, data approaching the limit of detection.

[23] For a description of bootstrapping techniques see, for example, Efron, B., The Jackknife, the Bootstrap and Other Resampling Plans, SIAM, CBMS-National Science Foundation Monograph, 38, 1982.

Bootstrap procedures often involve generation of more than 40 re-samples. This choice for the number of re-samples was based primarily on computational and time resource considerations, and also because of the ease afforded for calculating confidence intervals through the 2.5 and 97.5 quantiles of the 40 re-sample estimates (corresponding to the average of the lowest two and the highest two estimates, respectively).

The basic approach consists of five steps:

- Assume a binomial/lognormal mixture model for the concentration distributions;
- Generate appropriate probabilities as the inverse of Survey weights for the re-sampling plan;
- Generate 40 re-samples of size equal to the effective sample size;
- Use the maximum likelihood estimation procedure to estimate the parameters of the mixture model for each of the 40 re-samples; and
- Calculate estimates and 95% confidence intervals for relevant parameters using the 40 re-sample estimates.

Due to the comparatively large number of nitrate detections in the NPS, the procedure used for estimating nitrate concentration distributions is fairly robust. Minor modifications to the procedure, such as using means as opposed to medians from the 40 re-sampled estimates, do not substantially alter the numerical results.

The case for DCPA acid metabolites is not as straightforward as that for nitrate. There are sufficient numbers of DCPA acid metabolites detections in the CWS well survey so that the current methods can be used. However, there are not sufficient DCPA acid metabolites detections to enable the maximum likelihood procedure to converge for all the re-samples. The maximum likelihood procedure performs poorly or does not converge at all if there are a relatively small number of positive data points (detections), or the data points are grouped closely together or are all in the tail of the distribution. Discussion of the re-samples that do not converge and their effect on the analysis can be found in Chapter 4.

2.2.4.8 Method for Generating National Population Exposure and Risk Estimates

This section provides a discussion of methods used to develop population exposure estimates from information about the populations that drink CWS or rural domestic well water.

Survey weights are employed in the modified-bootstrap procedure to estimate CWS and rural domestic well concentration distributions. Two possible methods can be used to modify that basic approach to arrive at population estimates. The first, and most simple, is to assume a constant average number of people served by each well nationally, and to make the appropriate transformation of the estimated well concentration distribution to generate a "people" concentration distribution. This approach can provide biased estimates of population exposure to the extent that the number of people associated with a well is related to pesticide or nitrate detections or concentrations.

The second approach is to use available population data to create "people weights" from the Survey well weights. This method explicitly accounts for the number of people associated with each well, and provides more precise population exposure estimates when the number of people associated with a well is a good predictor of analyte detections or concentrations. The population of the household supplied by the well was addressed specifically in the Main Questionnaire for the rural domestic well survey. A similar question was not asked in the CWS well survey. The most appropriate surrogate in the CWS well survey is a question concerning the size of the system in terms of its total number of wells. External data from a report of a 1986 national survey of community well systems conducted by Research Triangle Institute[24] provides sufficient information to estimate an average value for the CWS population served given the number of wells in the system. Once "people weights" are developed, the modified bootstrap and maximum likelihood estimation procedures can be employed, as they were used for well concentration distributions.

Although population data are available from the rural domestic well Main Questionnaire, they are not in a form that is entirely conducive for use in assessment of population exposure. Two relevant questions pertain to the number of people in the household served by the well (wells were identified through telephone interviews directed at households in the rural domestic well survey), and whether or not the well water is used for drinking. Other issues concerning the extent of use, the number of people who drink the well water, the number of households served by the well, and the number of wells that serve the household, were not addressed. If the well is used to provide drinking water then all members of the household are assumed to drink the water, and exactly one well is assumed per household. The extent to which these assumptions are violated is not likely to significantly alter conclusions resulting from the rural domestic well exposure analysis.

Assumptions related to developing "people weights" for the CWS well survey are not as straightforward. The information available to perform this task consists of the following three items:

- The number of operating wells in the CWS represented by the sampled well (from question 9 in the Team Leader Introduction Questionnaire);
- The CWS survey well weights; and
- Information on the median number of wells associated with systems that serve certain population categories from EPA's 1986 Survey of Community Water Systems.

The first two items are used initially to create "system weights" by dividing the well weight by the number of operating wells per system to avoid double counting. This adjustment ensures that population estimates are not biased upward.[25]

EPA's 1986 Survey provides an estimated range of the number of wells per system for 12 population categories ranging from 25-100 people to over 1,000,000 people.[26] The average number of wells in systems serving those categories ranged from 1.5 wells per system for the first category (serving 25-100 people), to 204 wells per system for the largest category (serving over 1,000,000 people). Two regression lines were fit to these data, one for the low value in each population category, and one for the high end of each population category. Logarithmic transformations were necessary to provide a good fit. For each CWS well sampled in the NPS, the number of wells in the system, according to the Team Leader Introduction Questionnaire item, was used to predict the population by using each of the two estimated regression models. These regression models provide two extreme estimates for the population served by the system. A geometric mean was calculated from the two extreme values. This value served as the number of people served by the system of the sampled well, and was multiplied by the "system weights" to arrive at population weights. The "people weights" reflect the estimated number of people served by a CWS well and assume that each well serves only those people without any mixing of water from other wells in the system or from other surface water sources in the system. For rural domestic wells, each well serves a given number of people, estimated for each well from the Household Questionnaire. For CWS wells, each well independently serves a given number of people, estimated from the 1986 RTI Survey and the Team Leader Introduction Questionnaire. The only required information on other wells was the total number of wells in the system which was needed to estimate the total number of individuals served by the system, using RTI's data. Estimating the total number of individuals in the system makes it possible to estimate the mini-population of each well. This was regarded as the most reasonable approach to assessing CWS exposure, given that information on the quality of water in other wells in the system or other water sources in the system were unavailable.

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[24] Final Descriptive Summary, 1986 Survey of Community Water Systems, Report number RTI/7805/02-02F, Research Triangle Institute, October 1987.

[25] The system weights lead to an estimate of 35,800 community water systems nationally that provide ground water. This is similar to the estimate of 38,300 provided in the Phase I Report.

[26] The full list of population categories consists of: 25-100; 101-500; 501-1,000; 1,000-3,300; 3,301-10,000; 10,001-25,000; 25,001-50,000; 50,001-75,000; 75,001-100,000; 100,001-500,000; 500,001-1,000,000; and over 1,000,000.

For the purposes of the risk analysis the infant population is defined as children under one year of age. Infant data are available in the form of estimates of the average number of children per household by household population size. This data comes from the the Bureau of the Census "Current Population Reports" of the 1990 Census of Household and Family Characteristics. The data is reported in categories of number of people living in a household. For example households in which two people live comprise 55,212,000 people, 206,000 of which are infants. The overall population living in households is 235,499,000, of which 3,443,000 are infants. This corresponds to a population with a proportion of 1.46% infants. This proportion could be used to adjust the concentration distributions developed from the "people weights" to arrive at estimates for the infant population.

To generate infant population exposure estimates relevant quantile estimates from the estimated nitrate concentration distributions based on "people weights" were multiplied by the infant proportion factor of 1.46%

Method for Calculating Drinking Water Exposures

Adult exposures to nitrate and DCPA in drinking water obtained from NPS rural domestic wells were calculated using the following equation:

$$ADE = (C \times IR \times ED)/(BW \times AT)$$

where

ADE = lifetime average daily exposure (mg/kg/day)

C = concentration of the analyte (mg/L)

IR = intake rate

ED = exposure duration

BW = body weight

AT = averaging time

For nitrate and DCPA, which have not been associated with the potential development of cancer Averaging Time (AT) in the above equation equals the exposure duration. This equation yields Average Daily Exposures (ADE). Adult exposures were calculated for DCPA; however, infant exposures were calculated for nitrate, since infants are especially sensitive to the effects of nitrate exposure.

The following assumptions were made in the development of drinking water exposure estimates:

- Adults drink 2 liters of water per day and infants drink 0.64 liters of water per day;
- Values for the exposure duration parameter in the LADE/ADE equation were assumed to be 70 years for adults and 1 year for infants;
- Values for the body weight parameter in the LADE/ADE equation were assumed to be 70 kg for adults and 4 kg for infants; and
- Values for the lifetime (averaging time) parameter in the LADE/ADE equation were assumed to be 70 years for adults and 1 year for infants.

The values used for the above terms (intake rate, exposure duration, body weight, and lifetime) are EPA's standard assumptions used when determining health-based limits for drinking water.

Drinking water from rural domestic wells and community water systems is assumed to undergo no treatment prior to consumption. That is, treatment efficacy is assumed to be zero; the concentration of an analyte in drinking water at the tap is assumed to be the same as that detected at the wellhead; and, no loss of analyte due to volatilization or chemical degradation (e.g., hydrolysis) from the wellhead to the tap is assumed. These are reasonable assumptions given the information collected in the questionnaires regarding water treatment and the chemical properties of analytes used in the analysis.

Method for Calculating Noncancer Risks for Nitrate and DCPA Acid Metabolites

Noncancer risks were calculated for the analytes DCPA acid metabolites and nitrate using the following equation:

HI = ADE/RfD

where

HI = the Hazard Index

ADE = average daily exposure (mg/kg/day), as defined above

RfD = the oral reference dose for chronic exposures (mg/kg/day)

The RfD indicates a level below which adverse, noncancer effects are not expected to occur over a lifetime exposure to the chemical. The Hazard Index (HI) is used to measure noncancer risks; when HI > 1, a risk of developing adverse, noncancer effects may exist.

The RfD values for nitrate (1.6×10^{0} mg/kg/day) and DCPA acid metabolites (5.0×10^{-1} mg/kg/day) were obtained from: (1) "Health Effects Assessment Summary Tables" (HEAST) (USEPA 1990); (2) "Health Advisories" (HA), (USEPA 1987 and 1988); (3) Integrated Risk Information System (IRIS 1991); and (4) EPA's Office of Drinking Water "Reference Dose Cover Sheet for Nitrate," 1990. Note that the RfD value used for DCPA acid metabolites is actually the RfD for the parent compound DCPA. No RfD is available for the acid metabolites; therefore, it was assumed that the RfD for these compounds would be similar to that for the parent compound. A high confidence rating is given for this RfD since there are several studies that support the data used in its derivation (IRIS 1991).

The chronic oral RfD for DCPA of 0.5 mg/kg/day is based upon kidney and adrenal gland effects in long-term laboratory studies with rats and dogs. A medium confidence rating is given for this RfD because the rat bioassays are flawed to some extent (IRIS 1988).

The chronic oral RfD for nitrate of 1.6 mg/kg/day is based upon development of methemoglobinemia in infants (0-3 months old).

Method for Calculating Any Pesticide Exposure

Estimates of numbers of wells and percentages of wells containing at least one pesticide above health-based levels and of populations exposed to at least one pesticide above health-based levels were not based on concentration models, but on estimates of the number of sampled wells containing pesticides and estimates of the populations served. The estimates and confidence intervals were generated by application of the sample design through the sample weights to appropriate sample statistics. The estimates are the weighted sum of the sample statistics, calculated using the same procedures as were followed in preparing the similar estimates in the Phase I Report.[27]

Limitations of the Basic Approach for Generating Concentration Distributions

Development of concentration distributions is limited by two factors: the NPS data and the limitations of the statistical method.

First, the NPS was not designed for the purpose of generating concentration distributions for use in exposure and risk assessment. Although concentration distributions can be developed for wells, it is not clear how to incorporate information on populations that drink the well water. Neither the CWS or rural domestic well surveys were designed to obtain direct population information to perform this task, though the rural domestic well survey does provide some useful information (i.e., the number of people in the household served by the sampled well and whether or not the sampled well provides water used for drinking). Assumptions and approximations, many of them standard EPA procedure, had to be made to overcome the inadequacy of the NPS data for assessing population exposure and risk estimates.

In addition, NPS well water samples were analyzed by contract laboratories that maintained a minimum reporting limit for each analyte (see the NPS Phase I Report). All positive detections above the minimum reporting limit for an analyte also were analyzed on a second GC column. The primary quantification for a detected analyte was retained if the secondary results were within 25% of the primary result, otherwise the detection was reported without quantification. In one case, quantification was considerably different in the primary and secondary analyses, which could affect the estimated concentration distributions.

Apart from the primary analysis detections, approximately ten percent of the NPS samples were reanalyzed by referee laboratories to determine the extent to which primary analysis resulted in non-detection, and secondary analysis resulted in detection. Of these referee analyses, two cases recorded detections and these were near the MRLs for these analytes. Exhibit 6 of Appendix E of the NPS Phase I Report, reports the false negative rate for atrazine as 1 out of 108, and the rate for DCPA acid metabolites as 1 out of 133.

Second, although the modified bootstrap procedure seems reasonable, given appropriate weights, the procedure has not been tested extensively beyond its application here. Furthermore, the maximum likelihood procedure can produce unexpected results when the concentration data consists of too few positive observations or the data are grouped too closely together. This is particularly true if the data are in the tail of the distribution. There are too few DCPA acid metabolites detections for the maximum likelihood estimation procedure to converge[28] to correct estimates of the concentration models for rural domestic wells. This problem is exacerbated by using the effective sample size, and hence effective detection size, in the re-sampling plan to appropriately control variance estimation. Therefore, a traditional bootstrap procedure was used to estimate the DPCA acid metabolites distribution for rural domestic wells.

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[27] NPS Phase I Report, Appendix B, pp. B-52 to B-62.

[28] The maximum likelihood estimation procedure is an iterative procedure that converges, under appropriate conditions, to the maximum likelihood estimates. The amount of positive data and the grouping and position of those data relative to the mode of the lognormal component of the concentration distribution determine if appropriate conditions are present.

The necessity of using the Survey weights to develop concentration profiles is not clear. The Survey weights were developed based on stratification variables that were anticipated to affect pesticide occurrence in well water. The corresponding statistical assumption is that wells within strata are exchangeable with respect to pesticide detection, but wells between strata are not. The stratification variables, however, were not intended to delineate nitrate detections or concentration patterns, though they were expected to be associated with changes in pesticide detections and concentrations. The stratification variables did not, however, predict pesticide detections (see Chapters 3 and 4), and they predicted nitrate detections in unexpected ways. This suggests that the stratification variables cannot be used to distinguish wells that have greater pesticide or nitrate concentrations, and that weights based on the stratification variables may confound, rather than assist, development of concentration distributions.

For consistency with other NPS analyses, the Survey weights were incorporated into the development of concentration distributions. The design, however, was not incorporated. That is, the modified bootstrap procedure re-samples in proportion to the inverse of the weights for the whole population to generate a re-sample of size equal to the effective sample size. An alternative approach, which incorporates the design, is to re-sample in proportion to the inverse of the weights within primary sampling units. Re-samples can then be generated for each primary sampling unit of size equal to the effective sample size of that unit. The primary sampling unit re-samples can then be combined to form a single re-sampled data set. For the rural domestic well data, this approach can be expected to yield qualitatively similar results to the more simple approach actually used, since design effects are similar across primary sampling units. For the CWS well survey, this approach cannot be used since primary sampling units often consist of a single community water system that contains one well. Other similarly motivated re-sampling plans could be used, (for example based on the strata), but considering that the statistical method is in its infancy and that results for these types of modified bootstrap re-sampling methods are likely to be similar, the more simple approach was adopted.

Distributions other than the lognormal distribution also are characterized by long right tails (for example, the Gamma and Weibull distributions) and may provide better fits for the data. Use of different basic models could substantially alter the results, including those for population exposure and risk. Finally, the model used for this analysis is a binomial/lognormal mixture model, but this model does not account for other predictive factors (for example, the results presented in Chapter 3 indicate that there are many factors that influence nitrate detections and nitrate concentrations). A better model may incorporate predictive factors in the modeling process.

As previously discussed, the models incorporate a parameter representing the probability of non-occurrence. For these models there is an implicit assumption that some wells do not contain contaminants. For DCPA acid metabolites this is clearly a reasonable assumption, since it does not occur naturally. The assumption applied to nitrate, which does occur naturally, implies that nitrate does not occur in all wells. Available data from the NPS and other monitoring surveys indicate that this is a reasonable assumption for nitrate.

Estimation of concentration distributions for CWS wells requires assumptions about how the occurrence of NPS analytes is correlated among multiple wells within systems. A CWS well belongs to a system which may contain any number of wells (the largest system sampled in NPS contained 228 operating wells at the time of sampling).

Estimating concentration distributions for CWS wells requires making an assumption about the intra-system correlation of pesticide and nitrate occurrence in CWS wells. Assumptions of zero or complete correlation can be made to provide bounds for the estimates. CWS wells within systems are further defined by the clusters or groups within systems. Typically there are 4-6 wells in a cluster for large systems. Wells within a cluster are in close proximity (< 1/2 mile) and often draw from the same recharge area. The correlation between these wells can be expected to be greater than the correlation between wells from different clusters. Clusters of wells also vary in their proximity and correlations between clusters probably depend on the distance between them. NPS does not contain enough information to adequately model this correlation structure. For the purpose of developing concentration profiles a simple assumption of zero correlation (i.e., independence) between CWS wells was made.

Limitations of Exposure and Risk Methodology

The exposure and risk methodology provides an estimate of the number of people potentially served by a sampled well. A number of problems were encountered in trying to use the results of the RTI 1986 Survey of community water systems:

- The empirical relationship between categories of number of people served and the mean number of wells in community water systems is a non-increasing function in the RTI 1986 Survey;
- There are very few observations in the RTI 1986 Survey for large systems (only 2 in the final category of over 1,000,000, and only 5 in the 500,001-1,000,000 category). That is, the RTI data, used in this way, are subject to large sampling errors that are not accounted for in the concentration distribution estimation procedure. These categories ultimately drive the exposure numbers yet they are estimated with the least precision;
- A population of 4,000,000 was used as the upper bound estimate of the number of people served by the largest systems because this was the largest population served in the NPS;
- The choice of 4,000,000 as an upper bound for the largest population category may influence population exposure results by several hundred thousand people for each contaminated well sampled from systems serving at least 1,000,000 people. For example, use of 2,000,000 instead of 4,000,000 results in a decrease in the population estimate of approximately 600,000 people for each contaminated well in systems serving over 1,000,000 people; and
- Some community water systems use both ground water and surface water. Estimating the number of people served by wells in these systems is more difficult. The analysis assumed that the population that drinks water from CWS wells does not also drink from surficial sources.

The extent to which community water systems that use ground water use other sources of water makes estimating exposure more difficult. The RTI 1986 Survey indicates that fewer than 50% of CWSs use 100% ground water. Large systems get most of their water from other sources such as surface water. If other sources of water are mixed with the ground water then the exposure due to ground water only is lessened. Either fewer people than the CWS population of drinkers are exposed (because some drink ground water and some drink surface water) or the concentration to which they are exposed due to ground water is lower than the concentration in one well (unless other wells in the system have higher concentration levels). The RTI 1986 Survey Report does not contain sufficient information to assess adequately the percent of a CWS that uses ground water. For the development of concentration profiles, a simple assumption of no mixing of ground water with surface water was made.

The RTI Survey Report indicates that, on average, there are 2.8 wells per CWS that provide predominantly ground water, whereas NPS estimates suggest that there are approximately 94,600 wells in 35,800 community water systems nationally, i.e., approximately 2.6 wells per system. This difference may be due to the exclusion of "primarily surface water" systems from the RTI 1986 Survey data used for this analysis.

Issues related to intra-system correlation structures and mixing of both well water and ground and surface water were treated by using standard EPA assumptions in the concentration distribution analysis. Population served by CWSs, estimated from the regressions using RTI's 1986 Survey results, were pro-rated to the system's wells, and the wells were assumed to be independent with respect to nitrate and DCPA acid metabolites occurrence.The wells are assumed to serve a separate mini-population. That is, each well is assumed to serve only a particular population, without mixing of water form other wells in the system or mixing of water from surface sources in the system. The effect of these assumptions on the results presented in Chapter 4 is not clear, though it seems likely that concentration levels to which people are exposed due to contaminated ground water are likely to be lower than concentration levels in individual wells that contain comparatively high levels of NPS analytes due to the potential for mixing of water supplies (assuming that the surface water is untainted).

For the CWS well survey, creation of infant weights that adjust for the small differences in proportions of infants in such large populations is not likely to result in more precise estimates. For the rural domestic well survey, however, "infant weights" could be created by adjusting the "people weights" for the proportion of infants in each category of household size. For example, zero infants would be assigned to households with only one person, and according to the 1990 Census data, 0.37% is the proportion of infants in households with two people, 2.54% is the proportion of infants in households with three people, after which the proportion of infants decreases to 1.11% for households with at least seven people. To the extent that occurrence of contaminants in rural domestic well water is associated with the number of infants in rural domestic well households an approach using "infant weights" may produce more accurate estimates. However, for consistency with the approach used for CWS wells, a transformation assuming an average proportion of 1.46% infants in the population was performed.

A further factor influencing the decision to use a constant proportion to represent infant populations was the frame used to construct the Census data. Particularly, only data for families living in households and single persons living alone are available to estimate the proportion of infants in the population. That data comprises approximately 235,499,000 people, which does not represent the entire population of the United States. A further factor that may introduce biases with respect to the exposure analysis is that the populations that drink rural domestic or CWS well water are substantially less than the population used to estimate the infant proportion. If the characteristics of either NPS Survey population are different from those for the nation as a whole, the infant proportion estimate may not be appropriate.

Chapter Three: Results

This chapter presents the results of analyses conducted to test hypotheses about the association of pesticide and nitrate detections[1] with a broad range of variables. Readers are expected to possess a good understanding of statistical concepts. Results are presented for major databases generated by the NPS, corresponding to data collected and used in DRASTIC coding, obtained from questionnaires, and obtained during the sampling and chemical analysis processes. This chapter also contains results for data obtained by EPA from sources outside the NPS that provide supplementary information about topics useful to the analysis, such as long-term precipitation patterns and estimates of pesticide use. Results are presented in this chapter for each database in order to provide a clear record of the analysis and results for subsequent researchers. Results are presented in Chapter 4 organized by four major factors expected to affect contamination: ground-water sensitivity; agricultural activities and pesticide and fertilizer use; transport; and physical/chemical characteristics. Readers whose primary interest is in the evaluation rather than derivation of results may wish to proceed directly to Chapter 4.

This chapter first presents the results of two analyses addressing the design and implementation of the Survey:

- Analysis of the association of stratification variables with detections (Section 3.1); and
- Analysis of temporal factors and their possible effect on Survey results (Section 3.2).

The chapter then presents the results of analyses of associations between:

- Detections and DRASTIC scores and subscores (Section 3.3);
- Detections and well characteristics or activities near the well (Section 3.4);
- Detections and pesticide applications in agricultural areas, urban areas, and golf courses (Section 3.5);
- Detections and measures of crop production and animal husbandry (Section 3.6);
- Detections and physical/chemical characteristics of well water (temperature, pH, electrical conductivity) at the time of sample collection (Section 3.7);
- Detections and chemical characteristics of pesticides (Section 3.8);
- Nitrate detections and pesticide detections (Section 3.9); and
- Detections and precipitation (Section 3.10).

Results are reported if they met a screening criterion of a significance level of 0.05 or below. Descriptive significance levels (p values) are also presented for results reported in this chapter. Appendix A reports additional results that did not satisfy this screening criterion but did have a significance level of greater than 0.05 and less than 0.10.

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[1] The term pesticide detections is used to represent detection of at least one pesticide or pesticide degradate for the remainder of this section.

3.1 Stratification Variables

The NPS used a stratified design by which 1349 wells were selected for sampling using probability-based sample selection techniques. First-stage stratification variables were a proxy for ground-water vulnerability measured using the Agricultural DRASTIC scoring method, and estimates of pesticide use were determined from proprietary data held by the EPA Office of Pesticide Programs and other sources. Exhibit 3-1 shows the 12 stratification categories, which were used to classify all counties in the U.S.

Exhibit 3-1

First Stage or County-Level Strata

Ground-Water Vulnerability	Pesticide Use			
	High	**Moderate**	**Low**	**Uncommon**
High	1	4	7	10
Moderate	2	5	8	11
Low	3	6	9	12

The NPS was conducted as two parallel surveys, one for community water system (CWS) wells and one for rural domestic wells. For the rural domestic well survey only, ninety counties were selected at the first stage and wells were further stratified at the second stage using an index that combined information from sub-county DRASTIC scores and information on cropping intensities. Areas within each county were defined by this index as "cropped and vulnerable".

A stratified design serves two purposes: to increase sampling efficiency over simple random sampling by grouping sampling units that are expected to have similar characteristics, and to increase the number of sampled units with desired characteristics. EPA chose a stratified design for the NPS believing that differences in hydrogeologic conditions and pesticide use would affect the percentage of wells with detectable levels of pesticides or nitrate. Oversampling certain strata would increase the number of sampled wells containing pesticides or nitrate. The analysis reported in this section tested that hypothesis. The three stratification variables, Agricultural DRASTIC score (hereafter DRASTIC), pesticide use, and the "cropped and vulnerable" indicator, were included in separate analyses to determine their level of association with nitrate or pesticide detections.

Exhibit 3-2 presents the proportions of nitrate and pesticide detections in each of the first stage strata for CWS wells and rural domestic wells, while Exhibit 3-3 shows the proportions of nitrate and pesticide detections associated with each of the first stage stratification variables.

Exhibits 3-2 and 3-3 show some surprising results, considering the design of the Survey. In particular, compared to the moderate, low, and uncommon categories, there are smaller proportions of nitrate detections in the high pesticide use categories for the rural domestic well survey. With the exception of stratum one, there also are smaller proportions of nitrate detections in the high ground-water vulnerability categories in both surveys. There is also a smaller proportion of pesticide detections in the high vulnerability category for the rural domestic well survey. These results suggest that stratification did not function as hypothesized, at least at the first stage. In contrast, Exhibit 3-4 suggests that the rural domestic well second stage stratification variable may have performed as expected for pesticides, although not for nitrate.

Exhibit 3-2

Proportion of Sampled Wells with Nitrate and Pesticide Detections by First Stage Strata

Pesticide Use Index	Ground-Water Vulnerability Index	First Stage Stratum	Proportion of Sampled Wells with Detections			
			Nitrate		Pesticides	
			CWS Wells	Rural Domestic Wells	CWS Wells	Rural Domestic Wells
High	High	1	0.346	0.397	0.023	0.007
High	Moderate	2	0.482	0.179	0.089	0.037
High	Low	3	0.200	0.374	0.200	0.076
Moderate	High	4	0.284	0.356	0.046	0.014
Moderate	Moderate	5	0.434	0.602	0.138	0.067
Moderate	Low	6	0.576	0.748	0.105	0.039
Low	High	7	0.408	0.536	0.062	0.033
Low	Moderate	8	0.498	0.634	0.138	0.052
Low	Low	9	0.643	0.740	0.096	0.083
Uncommon	High	10	0.342	0.498	0.171	0.036
Uncommon	Moderate	11	0.584	0.681	0.048	0.040
Uncommon	Low	12	0.700	0.579	0.135	0.000
Total			0.519	0.569	0.102	0.042

Exhibit 3-3

Proportion of Sampled Wells with Nitrate and Pesticide Detections by First Stage Stratification Variables

Stratification Variables	Nitrate		Pesticides	
	CWS Wells	Rural Domestic Wells	CWS Wells	Rural Domestic Wells
Pesticide Use				
High	0.384	0.270	0.100	0.033
Moderate	0.448	0.561	0.105	0.046
Low	0.533	0.634	0.103	0.054
Uncommon	0.574	0.604	0.100	0.029
Vulnerability				
High	0.356	0.468	0.093	0.027
Moderate	0.523	0.589	0.092	0.050
Low	0.619	0.658	0.121	0.044
Total	0.519	0.569	0.102	0.042

For the rural domestic well survey, Exhibit 3-4 shows the proportion of nitrate and pesticide detections for the "cropped and vulnerable" indicator (i.e., sub-county areas that have high ground-water vulnerability and greater than 25 percent of the land area used for agricultural production or moderate ground-water vulnerability and greater than 50 percent of the land area used for agricultural production).

Exhibit 3-4

Proportion of Nitrate and Pesticide Detections for the Rural Domestic Well Survey Second Stage Strata

"Cropped and Vulnerable" Indicator	Rural Domestic Wells	
	Proportion of Nitrate Detections	Proportion of Pesticide Detections
"Cropped and vulnerable"	0.525	0.054
Not "cropped and vulnerable"	0.533	0.036

Exhibit 3-5 presents the results for tests of association between detections and stratification variables (p-values in this exhibit are not restricted to ≤ 0.05). The tests confirm that there are few significant relationships between nitrate or pesticide detections and the stratification variables. Only the differences in proportions of nitrate detections across ground-water vulnerability categories in the CWS well survey and across pesticide use categories in the rural domestic well survey are significant at the ≤ 0.05 level but these

Exhibit 3-5

Association of Nitrate and Pesticide Detections with First and Second Stage Stratification Variables

	CWS Wells		Rural Domestic Wells	
Stratification Variable	Nitrate Detections p-value	Pesticide Detections p-value	Nitrate Detections p-value	Pesticide Detections p-value
Pesticide Use	0.087	0.994	< 0.0005	0.705
Ground-Water Vulnerability	< 0.0005	0.734	0.235	0.524
"Cropped and Vulnerable"	NA	NA	0.304	0.376

NA = Cropped and vulnerable stratification not performed for CWS wells.

are not in the expected direction. They correspond to a greater proportion of nitrate detections in low use and low vulnerability strata). The differences in proportions for pesticide detections for ground-water vulnerability and for the second stage strata in the rural domestic well survey are not statistically significant.

These results show that the NPS stratification did not effectively reduce the variance of sample estimates. Section 3.3 presents a more detailed investigation of the association of DRASTIC scores to pesticide and nitrate detections. Sections 3.4.3, 3.5, and 3.6 describe analyses of pesticide and fertilizer use measures.

3.2 Temporal Allocation

The EPA Scientific Advisory Panel (SAP), in its review of the NPS pilot study and final survey design conducted in September 1987, recommended that EPA design the study to minimize the effect of temporal (seasonal) variability on the Survey results. Two methods are available for controlling the effect of confounding factors such as temporal variability: stratification, and randomization. Both of these were used to control the effect of temporal variability in the NPS. Within each first-stage stratum, the water samples were spread throughout the term of the Survey. Drinking water wells to be sampled were randomly allocated to available two-week time periods covering the duration of the Survey. The analysis reported in this section evaluated whether the Survey successfully minimized confounding due to disproportionately sampling during a single month or season.

3.2.1 Temporal Randomization

The initial NPS temporal design was defined by 28 available two-week time periods. The initial CWS well sample design specified two-week time slots from June 1988 to August 1989. The initial rural domestic well sample design specified time periods from August 1988 to December 1989. Within each first-stage stratum, wells were randomly allocated to these time slots. This assured that laboratories could analyze a maximum of 40 samples within such time slot, but would not be overloaded by an excess of samples during any period. This temporal design does not correspond to full temporal randomization but was used to minimize the effects of temporal variability given the time and logistical constraints on the Survey.

During implementation, the Survey deviated from the initial temporal allocation for a variety of reasons (see the NPS Phase I report, Appendix B), but the underlying approach to temporal allocation was retained. How well the Survey minimized the effect of temporal variability was measured by comparing actual monthly allocation of wells to expectations under hypothetical random temporal allocation. Confidence intervals were calculated for the number of wells that would be expected to be sampled under random allocation, and these confidence intervals were compared to the actual NPS temporal allocation. The actual temporal variability of the NPS is less than indicated by these results, due to the control by first-stage strata. Sample sizes are too small to allow examination of temporal variability by stratum.

Under randomization (without regard to the planned Survey data collection period, laboratory capacity limits, or holiday seasons) the proportion of wells allocated to a particular month is expected to be one twelfth of the sample, but with a standard error related to the sample size as well as the proportion. The proportion may be regarded as a Binomial proportion[2]. The total normalized weighted frequency is the appropriate sample size for calculating the binomial confidence intervals required for comparison to the NPS sample. The confidence intervals were calculated using the normal distribution approximation to the binomial distribution. The 95% and 99% confidence intervals are presented in Exhibit 3-6.

Exhibit 3-6

Binomial Confidence Intervals for Random Temporal Allocation

Domain	Effective Sample Size	Proportion of Wells Allocated to Particular Month	C.I. Level	Lower Bound	Upper Bound
CWS	426.10	0.083	95%	24.33	46.69
CWS	426.10	0.083	99%	22.22	48.80
Rural	409.72	0.083	95%	23.18	45.11
Rural	409.72	0.083	99%	21.11	47.18

Wells were sampled during twenty-three months from April 1988 to February 1990. The monthly distribution of sampled wells, collapsed over the years spanned by the Survey, is provided in Exhibits 3-7 (CWS well survey) and 3-8 (rural domestic well survey). The normalized weighted frequencies are also provided in these exhibits. These frequencies employ the design effect to calculate the sample size required in a simple random sample that would provide the same Survey precision.

Exhibits 3-7 and 3-8 show that the CWS well survey sampled a comparatively high proportion of drinking water wells in the months of September, October, and November, and the rural domestic well survey sampled a comparatively high number of wells in January, February, October, and November.

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[2] The distribution of samples across months under randomization would be expected to follow a multinominal distribution with $\underline{p}_i = 1/12$ ($\underline{i}$ = 1 through 12). The single parameter marginals of the multinominal distribution are binomial with the same parameter value.

Exhibit 3-7

Monthly Distribution of Sampled Wells for the Community Water System Well Survey

Month	NPS Implementation		Comparable Random Sample	
	Wells	Percent	Weighted Frequency	Percent
January	34	6.3	26.60	6.2
February	39	7.2	33.94	8.0
March	31	5.7	25.29	5.9
April	40	7.4	32.14	7.5
May	45	8.3	34.96	8.2
June	27	5.0	19.67	4.6
July	21	3.9	17.66	4.1
August	33	6.1	27.45	6.4
September	78	14.4	61.49	14.4
October	88	16.3	69.70	16.4
November	73	13.5	54.57	12.8
December	31	5.7	22.62	5.3
Total	540	100.0	426.10	100.0

Exhibit 3-8

Monthly Distribution of Sampled Wells for the Rural Domestic Well Survey

Month	NPS Implementation		Comparable Random Sample	
	Wells	Percent	Weighted Frequency	Percent
January	114	15.2	56.97	13.9
February	86	11.4	43.28	10.6
March	29	3.9	19.77	4.8
April	43	5.7	28.19	6.9
May	33	4.4	21.36	5.2
June	53	7.0	26.82	6.5
July	41	5.5	23.64	5.8
August	34	4.5	19.25	4.7
September	60	8.0	33.44	8.2
October	102	13.6	52.44	12.8
November	115	15.3	64.49	15.7
December	42	5.6	20.10	4.9
Total	752	100.0	409.72	100.0

If the NPS temporal allocation had been random most of the months would be likely to have sample sizes between the calculated bounds shown in Exhibit 3-6.[3] Comparisons of the 95% confidence intervals presented in Exhibit 3-6 and the weighted sample allocation presented in Exhibits 3-7 and 3-8 show that at the 95% confidence interval for both the CWS and the rural domestic well survey the sample sizes in half of the months did not fall within these bounds. As the next section shows, however, there is insufficient evidence to suggest a temporal effect on pesticide or nitrate contamination in the NPS.

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[3] The confidence intervals presented in Exhibit 3-6 were calculated using the effective sample sizes. The confidence intervals apply to any particular month rather than all months together. Without these assumptions the confidence intervals would be narrower than those presented.

3.2.2 Temporal Analysis

To determine if there is a relationship between the month or season of well water sampling and pesticide or nitrate detections, EPA evaluated detections by month and for each of seven seasonal variables. The "all pesticides" group was used for this analysis. Exhibit 3-9 shows the proportion of nitrate and pesticide detections by month.

Exhibit 3-9

Nitrate and Pesticide Detections by Month

	CWS Wells		Rural Domestic Wells	
Month	Proportion of Nitrate Detections	Proportion of Pesticide Detections	Proportion of Nitrate Detections	Proportion of Pesticide Detections
January	0.53	0.101	0.51	0.001
February	0.61	0.063	0.50	0.077
March	0.53	0.124	0.52	0.045
April	0.62	0.109	0.45	0.039
May	0.39	0.168	0.43	0.032
June	0.38	0.029	0.58	0.066
July	0.45	0.183	0.63	0.019
August	0.62	0.101	0.69	0.100
September	0.57	0.087	0.59	0.013
October	0.48	0.064	0.63	0.057
November	0.50	0.125	0.63	0.048
December	0.50	0.165	0.66	0.030

Exhibit 3-10 presents the significance levels for tests of associations between detections and the monthly and seasonal variables, performed to determine whether pesticide or nitrate detections are associated disproportionately with particular months or seasons.[4] There is insufficient evidence based on these analyses to suggest a temporal effect on pesticide or nitrate detections in the NPS.

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[4] The analysis of pesticide detections by temporal variables was performed for the "all pesticides" group rather than on any groups of pesticides with smaller numbers of detections. Even so, the assumptions for the corresponding statistical analysis were not met because of the comparatively large number of groups (24) and the small number of pesticide detections. Other analyses of pesticide detections by seasonal variables also did not fully maintain the underlying assumptions.

Exhibit 3-10

Nitrate and Pesticide Detections by Temporal Variables in the Community Water System Well Survey

	CWS		Rural Domestic Wells	
Temporal Group[1]	Nitrate p-value	Pesticide p-value	Nitrate p-value	Pesticide p-value
Month	0.630	0.805[2]	0.916	0.080[2]
Season1	0.467	0.978	0.361	0.947
Season2	0.107	0.522	0.564	0.573
Season3	0.910	0.763	0.297	0.856
Season4	0.232	0.782	0.311	0.813
Season5	0.722	0.871	0.215	0.717
Season6	0.742	0.734	0.370	0.930
Season7	0.499	0.662	0.410	0.807

[1] **Season1** = {(JAN, FEB, MAR), (APR, MAY, JUN), (JUL, AUG, SEP), (OCT, NOV, DEC)}
Season2 = {(FEB, MAR, APR), (MAY, JUN, JUL), (AUG, SEP, OCT), (NOV, DEC, JAN)}
Season3 = {(MAR, APR, MAY), (JUN, JUL, AUG), (SEP, OCT, NOV), (DEC, JAN, FEB)}
Season4 = {(JAN, FEB, MAR, APR), (MAY, JUN, JUL, AUG), (SEP, OCT, NOV, DEC)}
Season5 = {(FEB, MAR, APR, MAY), (JUN, JUL, AUG, SEP), (OCT, NOV, DEC, JAN)}
Season6 = {(MAR, APR, MAY, JUN), (JUL, AUG, SEP, OCT), (NOV, DEC, JAN, FEB)}
Season7 = {(APR, MAY, JUN, JUL), (AUG, SEP, OCT, NOV), (DEC, JAN, FEB, MAR)}.

[2] May not be a valid test as the statistical assumptions underlying the test have not been met due to insufficient numbers of detections in some months.

The lowest significance level presented in Exhibit 3-10 is 0.080 for the analysis of pesticide detections by month in the rural domestic well survey.[5]

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[5] The procedures used are not adjusted for the number of hypotheses considered for the temporal analysis. It may be possible to find single comparisons that have low descriptive significance levels, but when many comparisons are performed on the same data set an adjustment to account for the number of comparisons is appropriate. For instance, an analysis of the difference in proportions of nitrate detections for the first six months versus the last six months in the rural domestic well survey yields a descriptive significance level of 0.082 based on that analysis alone. However, when numerous post hoc hypotheses are statistically analyzed using the same data the descriptive significance level over the set of comparisons must be considered, rather than the descriptive significance level of the individual comparison alone. An adjustment that accounts for the number of hypotheses tested on the same data has the effect of decreasing the significance obtained from a single comparison alone (i.e., increasing the descriptive significance level). While single comparisons can be found in the temporal data that yield low descriptive significance levels, the apparent significance may be attributed as much to maximizing the possibility of finding a single significant comparison as to evidence of an effect that warrants further study. Due to the comparatively high descriptive significance levels found in the temporal analysis, values are presented without adjustment. These results do not provide sufficient evidence to suggest a temporal effect.

3.3 Drastic as a Predictor of Drinking Water Well Contamination

The analyses reported in this section tested the hypothesis that a higher occurrence of analyte detections in drinking water wells is found in counties and sub-county areas with higher Agricultural DRASTIC scores. Higher positive total scores and subscores indicate greater pollution potential of aquifers.

County-level DRASTIC scores for CWS wells and DRASTIC scores at both the county and sub-county levels for rural domestic wells were examined for potential relationships with pesticide and nitrate detections. (Although DRASTIC is designed to score areas larger than 100 acres, an area as large as a county can be scored, with the results dependent in part on the time and effort expended and in part on the complexity of the area and the availability of data.) Both overall DRASTIC scores and scores for each of the seven individual DRASTIC subcomponents (DRASTIC subscores) were included. The following sections describe the analysis and results for the CWS well survey and the rural domestic well survey.

3.3.1 Evaluation of County-Level DRASTIC

County-level Agricultural DRASTIC scores and subscores were developed as part of the first stage stratification process for all 3,137 counties and county equivalents in the U.S. For the rural domestic well survey 90 counties were selected; 399 counties were selected for the CWS survey. Although the DRASTIC scores presented in this section differ from those used to develop the first stage strata, the qualitative results may be expected to be similar.[6] As Section 3.1 discusses, DRASTIC measured at the county level did not perform as anticipated. DRASTIC did not successfully identify areas of greater vulnerability to pesticide contamination. DRASTIC did identify areas of greater likelihood of nitrate contamination, but in the opposite direction to that expected.

The county-level DRASTIC scores and subscores were used to identify relationships between DRASTIC and pesticide detections for the "all pesticides" group, nitrate detections, and nitrate concentrations in CWS wells. Exhibit 3-11 provides a summary of the results of analyses between DRASTIC factors and pesticide and nitrate detections in CWS wells for the counties included in the CWS study.

The results presented in Exhibit 3-11 generally show that DRASTIC factors are poor predictors of pesticide and nitrate detections in CWS wells. Notable exceptions include the relationship between depth to water and pesticide detections, and between hydraulic conductivity and nitrate detections. Other effects with low significance levels (p-values) include the relationship of net recharge and aquifer media with nitrate detections. The correlation of these DRASTIC variables with nitrate detections is, however, in the opposite direction to that expected.

Analyses were performed to identify relationships between DRASTIC factors and nitrate concentrations given detection above the NPS minimum reporting limit for nitrate of 0.15 mg/L. These analyses used the logarithmic transformation of the nitrate concentrations. This series of analyses did not provide sufficient evidence of a relationship in the hypothesized direction for any of the DRASTIC variables.

These results confirm the findings, presented in Section 3.1, that Agricultural DRASTIC at the county level as applied by NPS is a poor predictor of pesticide detections in CWS wells. (It should be noted that Agricultural DRASTIC was designed to predict pesticide occurrence in ground water, not in individual wells.) These results also confirm the results for nitrate detections in CWS wells, presented in Section 3.1, that nitrate detections are inversely related to Agricultural DRASTIC factors.

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[6] The procedure followed in the DRASTIC scoring for the first-stage stratification is described in the NPS Phase I Report, pp. B6-B7. Stratification was based on weighted scores, although VARSCORES were prepared. Because the VARSCORE best accounts for intracounty variability, it was used for the analysis reported in this section.

Exhibit 3-11

Association of Pesticide and Nitrate Detections in Community Water System Wells with County-Level DRASTIC Measures*

DRASTIC Factors	Variable Name	Pesticide Detection		Nitrate Detection	
		Direction of Effect	p-value	Direction of Effect	p-value
Depth to water	DEPTH	+	0.011		
Net Recharge	RECHARGE			-	0.003
Aquifer media	AQUIFER			-	0.004
Hydraulic Conductivity	CONDUCTIVITY			+	0.001
Total DRASTIC score	WGTSCORE			-	< 0.0005
Adjusted WGTSCORE	VARSCORE			-	< 0.0005

* Blanks indicate no significant associations.

The procedures for scoring DRASTIC at the first stage were identical for both CWS and rural domestic well surveys. For the rural domestic well survey, ninety counties were selected for sampling. Sampled wells were selected from those counties. The first stage stratification variable developed from the DRASTIC scoring system did not perform as anticipated in the rural domestic well survey. That is, Agricultural DRASTIC as measured through the first stage stratification variable did not successfully identify areas of greater incidence of pesticide contamination. The topography variable was associated with nitrate detections. Exhibit 3-12 provides a summary of the results of analyses between DRASTIC factors and pesticide and nitrate detections in rural domestic wells.

Exhibit 3-12

Association of Pesticide and Nitrate Detections in Rural Domestic Wells with County-Level DRASTIC Measures*

DRASTIC Factors	Variable Name	Pesticide Detection		Nitrate Detection	
		Direction of Effect	p-value	Direction of Effect	p-value
Aquifer media	AQUIFER			-	0.034
Topography	TOPOGRAPHY			+	0.044

* Blanks indicate no significant associations.

The results presented in Exhibit 3-12 generally show that DRASTIC factors are poor predictors of pesticide and nitrate detections in rural domestic wells. The relationship between aquifer media and nitrate detections is contrary to the intended hypotheses.

Further analyses were performed to identify relationships between DRASTIC factors and nitrate concentrations. This series of analyses did not provide sufficient evidence of a relationship with pesticide concentrations in the hypothesized direction for any of the DRASTIC variables. There was, however, evidence of a relationship between topography and nitrate concentrations (significance level < 0.00005).

These results confirm the findings, presented in Section 3.1, that Agricultural DRASTIC at the county-level is a poor predictor of pesticide detections in rural domestic wells, even though Agricultural DRASTIC was designed to predict pesticide occurrence.

3.3.2 Evaluation of Sub-County-Level DRASTIC

Sub-county DRASTIC scores and subscores were developed as part of the second stage stratification process for the 90 counties in which sampling of rural domestic wells occurred.[7] Analyses of sub-county-level DRASTIC paralleled the procedures used for first stage DRASTIC analysis. Exhibit 3-13 summarizes the results of these analyses for pesticide detections and Exhibit 3-14 presents results for association of DRASTIC scores with nitrate detections.

Exhibit 3-13

Association of Pesticide and Nitrate Detections in Rural Domestic Wells with Sub-County DRASTIC Measures*

DRASTIC Factors	Variable Name	Pesticide Detection		Nitrate Detection	
		Direction of Effect	p-value	Direction of Effect	p-value
Aquifer media	AQUIFER			-	0.036
Impact of vadose zone	IMPACT	+	0.020		
Hydraulic Conductivity	CONDUCTIVITY			-	0.006

* Blanks indicate no significant associations.

The results presented in Exhibit 3-13 generally show that DRASTIC factors at the sub-county-level are also poor predictors of pesticide and nitrate detections in rural domestic wells. The most noticeable exception concerns the relationship between the impact of vadose zone media and pesticide detections. Other effects that are apparent are the relationship of aquifer media, and hydraulic conductivity with nitrate detections. The correlation of these DRASTIC variables with nitrate detections is in the opposite direction to that expected.

Further analyses were performed to identify relationships between sub-county DRASTIC factors and nitrate concentrations in wells. This series of analyses used the logarithmic transformation of nitrate concentration. Results are reported in Exhibit 3-14.

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[7] The second-stage stratification for rural domestic wells is described in the NPS Phase I Report, pp. 18-21. In the 90 counties, "cropped and vulnerable" and not "cropped and vulnerable" sub-county areas were identified using DRASTIC scores and estimates of agricultural activity. Sub-county DRASTIC scores were not prepared for the CWS survey.

Exhibit 3-14

Models of Relationship of Sub-County DRASTIC Factors and Nitrate Concentrations for Rural Domestic Wells*

DRASTIC Factors	Variable Name	Estimated Intercept	Estimated DRASTIC Factor Coefficient	p-value
Aquifer media	AQUIFER	–0.542	0.047	0.006
Topography	TOPOGRAPHY	–0.714	0.046	< 0.0005
Total DRASTIC score	WGTSCORE	–0.760	0.007	0.014

* Nitrate concentrations have been logarithmically transformed.

Although there was insufficient evidence of associations in the hypothesized direction between DRASTIC factors at the sub-county-level and nitrate detections in drinking water wells, there is some evidence in support of associations with nitrate concentrations in the manner expected by the DRASTIC system. In particular, there is strong evidence that nitrate concentrations are related to aquifer media, topography, and total DRASTIC scores. Possible explanations of the difference in performance of the two approaches to modeling nitrate associations include: (1) nitrate occurs in groundwater at very low concentrations, the DRASTIC scoring system may not be effective in predicting the presence of nitrate in drinking water wells at low concentrations (including zero); and (2) logistic regression models are not appropriate for the full range of nitrate concentrations (i.e., greater than zero concentration). Since the sub-county DRASTIC results are not supported by the county-level DRASTIC results for rural domestic wells or CWS wells, these possible explanations pertain to sub-county DRASTIC only. Because nitrate detections and concentrations are recorded only at levels above the minimum reporting limit of 0.15 mg/L, resolution of the possible explanations using NPS data is not possible.

The sub-county DRASTIC results parallel the findings, presented in Section 3.1 for second stage stratification, that no relationship could be demonstrated between Agricultural DRASTIC scores at the sub-county level and pesticide detections in rural domestic wells. These results similarly confirm the results for nitrate detections in rural domestic wells at the second stage that nitrate detections are not related to Agricultural DRASTIC factors. However, nitrate concentrations were found to be related to three DRASTIC factors.

3.4 Well Characteristics and Activities Conducted Near the Well

This section presents the results of the statistical analyses of the relationships between detections of nitrate or at least one pesticide or pesticide degradate in CWS and rural domestic wells and factors such as well location and construction, local land uses, and local land features. The data used for these analyses consist of pesticide and nitrate detections above the minimum reporting limits of the NPS and responses to detailed questionnaires obtained from homeowners or residents, community water system owners or operators, local area experts, and well samplers. The questionnaires were reviewed by hydrogeologists and soil scientists to identify site-specific cropping practices and pesticide use patterns that could generate useful hypotheses for statistical testing. The hypotheses tested include the following:

- Analytes are detected more frequently in areas of high pesticide use;
- Analytes are detected more frequently in shallow and/or not optimally constructed and/or old wells;
- Analytes are detected more frequently in areas where non-farm pesticides are used;
- Crops or crop types are good indicators of pesticide or nitrate contamination;
- Point sources of contamination (septic tanks, pesticide spills, pesticide and fertilizer dealerships, and disposal sites) are good indicators of contamination; and
- Analytes are detected more frequently in areas where irrigation is used.

Section 3.4.1 provides a brief discussion of the data sources and statistical methods used, Section 3.4.2 provides details of the results of the ensuing statistical analyses, and Section 3.5.3 describes a review of reported pesticide use activities and the relationship between reported pesticide use and pesticide detections.

3.4.1 Data Sources and Statistical Methods

Data regarding well location and construction, activities occurring near the well, and local land features were obtained primarily from questionnaires administered prior to, or at the time of, well sampling. Three detailed questionnaires were completed during well sampling at both CWS and rural domestic wells. These sets of questionnaires contained similar items for the two surveys[8]:

- **Team Leader Introduction and Well Observation Record.** The Team Leader Introduction (TLI) contains questions about well water treatment, septic systems, and diagrams of local land features within 300 feet of the well (such as drainage ditches, farmland, wooded areas, bodies of water, paved areas, buildings, or other wells). The Well Observation Record (WOR) contains questions about the well and the surrounding area, including topography, soils, and well protection. The TLI and WOR were administered together as one questionnaire. Responses for this questionnaire were provided primarily by well operators and well owners.
- **Main Questionnaire.** These questionnaires contain detailed questions about well construction, non-farm and farm pesticide use, and nitrogen fertilizer use on the property where the well is located. This questionnaire was administered primarily to well operators and well owners.
- **Local Area Questionnaire.** This questionnaire was predominantly administered to county agricultural extension agents following well sampling to collect information about local conditions within one-half mile of the well. Information was collected on crops grown, pesticide use, local land features such as water bodies, landfills, and chemical manufacturing facilities, and irrigation practices.

In addition to these questionnaires, a fourth questionnaire was administered prior to the sampling of rural domestic wells. This instrument, the **Second Stage County Agent Questionnaire**, was administered to county agricultural extension agents as part of the second stage stratification process. Information was collected on crops grown, pesticides used, and local soil characteristics within the United States Geological Survey (USGS) 7.5 minute quadrangle area containing the sampled wells.

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[8] See NPS Phase I Report Appendix D for copies of the questionnaires.

Most questions permitted only yes or no as a response. For example, a typical question was "Is the property on which the well is located used for farming?". Other questions allowed a broader set of categories as possible responses. For example the question "What is the predominant soil condition within 300 feet of the well?" allowed seven different responses ranging from clay soil to sandy/silty soil. A few questions required numerical answers describing, for instance, the depth of the well or the year of well construction. Analysis of the relationship between items corresponding to the first two cases (categorical responses) and pesticide or nitrate detections consisted primarily of chi-square procedures. Analysis of the relationship between well depth or year of construction and pesticide or nitrate detections consisted primarily of univariate logistic regression analysis with the continuous variables as the explanatory (independent) variable. Exploratory analyses were performed in all cases to verify that statistical assumptions underlying these tests were adequately satisfied. The procedures used are described in more detail in Chapter 2 of this report.

3.4.2 Results of Analysis of Questionnaire Items

This section presents the results of analyses of associations of pesticide and nitrate detections with well characteristics and activities reported near sampled wells. Results are presented in the following order:

- Analyses of the relationship of questionnaire variables and nitrate detections for CWS and rural domestic wells;
- Analyses of the relationship of questionnaire variables and pesticide detections for CWS and rural domestic wells; and
- Summary of results including comparisons of results for pesticide detections and nitrate detections.

The first two subsections include discussions of the analyses involving questionnaire items in the following general categories of well characteristics and activities conducted near the well. Questionnaire items are described and the source questionnaire and item number are provided in the table of results. The questionnaires addressed the following topics:

Farming practices, including agricultural pesticide use and nitrogen fertilizer use. Questions concerning farming practices were posed in the Main and Local Area Questionnaires. Questions included Main Questionnaire items about farming, pesticides used for farming, farm fertilizer use, and pesticide storage on the property where the well is located, and Local Area Questionnaire items about crops farmed and land used for pasture within one-half mile of the well.

Non-farm pesticide use. Questions concerning non-farm pesticide use around the home or in the vicinity of the sampled wells came from both the Main and Local Area Questionnaires.

Well construction characteristics. Well characteristic information was collected using the Well Observation Records and the Main Questionnaires. These questions prompted responses about well protection, well construction (casing, grouting, surface closure, drilling, and age), well depth, and recent problems with well operations.

Use of septic systems. Information about septic systems used near the well was collected from the Team Leader Introductions and Local Area Questionnaires, and from the rural domestic well Main Questionnaire. These questions pertained explicitly to septic tanks, septic fields, cesspools, and water disposal ponds.

Local land area conditions. Information about land features near the well was drawn from the Well Observation Records, and included questions about local topography and predominant soil condition.

Type of aquifer (CWS well survey only). The CWS Main Questionnaire asked whether the CWS wells draw water from confined or surficial aquifers.

Water bodies near the well. The Local Area Questionnaire contained a series of questions pertaining to water bodies within one-half mile of the sampled wells. Water bodies included streams, rivers, irrigation canals, reservoirs, lakes, bays, springs, ponds, and drainage ditches. Some questions distinguished between lined and unlined water bodies. Questions about drainage ditches and bodies of water in general were also contained in the Well Observation Record.

Irrigation. Questions about irrigation practices were included in the Local Area Questionnaires. These questions covered types of irrigation and sources of water for irrigation, but did not ask about amounts of water used for irrigation.

Facilities near the well. The Local Area Questionnaire contained a series of questions pertaining to installations within one-half mile of the sampled wells. Installations considered included chemical plants, airports, military bases, waste sites, landfills, waste treatment facilities, golf courses, and pesticide retail outlets.

Water treatments applied to well water. A series of questions about treatment of the well water prior to drinking was administered in the Team Leader Introductions for both surveys, and included questions about use of water softeners, filters, chlorine treatment, and carbon or charcoal treatment. (The water samples in the NPS were always taken prior to treatment.)

The responses obtained on NPS questionnaires and used in the analysis of questionnaire items were not validated from other independent sources. Questionnaire responses were reviewed for internal consistency. Results of field interviewer debriefings that provide information about the quality of the questionnaire results are provided in Chapter 4.

3.4.2.1 Analysis of Nitrate Detections and Questionnaire Items

Nitrate is the analyte most frequently detected in both the CWS and rural domestic well surveys. Survey results indicate that over half of the CWS and rural domestic wells in the United States contain nitrate (measured as N) at or above the Survey's minimum reporting level (MRL) of 0.15 mg/L. This section discusses the analysis of associations between nitrate detections and factors such as well construction, well location, and activities conducted in the vicinity of the well. Results are presented first for the CWS well survey, and then for the rural domestic well survey. This section concludes with a summary of the results including a comparison of CWS and rural domestic well survey results.

CWS Well Survey Results

Exhibit 3-15 provides a summary of factors that are related to nitrate detections in CWS wells. Farming (CWS Main Questionnaire (item C.1)) is related to nitrate detections. This conclusion is not substantiated by analysis of the other farming-related questions.

Analysis of responses to questions about well characteristics (such as well casing, grouting, etc.) did not, in general, show evidence of a relationship with nitrate detections.

Exhibit 3-15

Factors from NPS Questionnaires Associated with the Probability of Detecting Nitrate for Community Water System Wells

Factor (with Source Questionnaire and Item)	Direction of Effect	Significance Level (p-value)
Property where well is located farmed since Jan. 1, 1984.* (Main C.1)	+	0.022
Flood irrigation methods used within one-half mile of the well. (LAQ 14b)	+	0.019
Well draws water from unconfined aquifer(s). (Main A.25)	+	0.006
Drainage ditch within 300 feet of the well. (WOR 6a)	-	0.030
Lined drainage ditch within one-half mile of the well. (LAQ 12e)	-	0.019
Unlined water bodies within one-half mile of the well. (LAQ 12a, b, d, g, h, i, j, k, l)	-	0.010
Water Disposal Pond within one-half mile of the well. (LAQ 11e)	-	0.003
Water treatment applied to the water from the well. (TLI 13a, b, c, d, e, f)	-	< 0.0005

TLI = Team Leader Introduction
WOR = Well Observation Record
Main = Main Questionnaire
LAQ = Local Area Questionnaire

* For wells sampled after March 5, 1989, this question was asked about farming since January 1, 1985.

Analysis of well depth indicated a relationship with nitrate detections and nitrate concentrations. The total distance from the ground surface to the bottom of the well was collected from question A.5 in the CWS Main questionnaire. Results for the relationship between well depth and nitrate detections are presented in Exhibit 3-16. There is a clear relationship between nitrate detections and well depth in the CWS well survey, i.e., there is a greater chance of nitrate contamination in shallow wells. Furthermore, there is sufficient evidence to suggest that higher concentrations of nitrate are found in shallow wells. The average well depth for wells containing nitrate at concentrations above the minimum reporting limit is 310 feet for CWS wells, compared to an average depth of 434 feet for wells in which nitrate was not detected.

Exhibit 3-16

Models of the Relationship Between Nitrate Detections* and Concentration and Well Depth in Community Water System Wells

Dependent Variable	Explanatory Variable	Estimated Intercept	Standard Error	Estimated Well Depth Coefficient (ℓn Feet)	Standard Error	ℓn(Feet) Coefficient Significance Level (p-value)
Nitrate Detection	ℓn(Well Depth)	348	0.621	–0.414	0.132	< 0.0005
ℓn(Nitrate Concentration)	ℓn(Well Depth)	1.388	0.467	–0.213	0.087	0.015

* Nitrate concentrations have been logarithmically transformed.

Information on the year in which sampled wells were originally constructed or drilled was collected from question A.1 in the CWS Main Questionnaire. Logistic regression analyses were performed to determine the extent of the relationship between year of well construction and both nitrate detections and nitrate concentrations. There is insufficient evidence based on this analysis to suggest that the year of construction is associated with nitrate detections. The average number of years since construction for wells containing nitrate at concentrations above the minimum reporting limit is 24.5 years in CWS wells, compared to an average age of 23.3 years for wells in which nitrate was not detected.

Statistical analysis involving data collected about topography, soil type, and other land features within 300 feet of the well did not show evidence of an association with nitrate detections.

Analysis of the CWS aquifer question revealed that the proportion of nitrate detections in the unconfined aquifer group (62.6%) is significantly greater than the proportion in the confined aquifer group (44.7%). These results indicate that unconfined aquifers are more at risk of nitrate contamination than confined aquifers.

Analysis of questions related to water bodies indicate that there is a lower chance of detecting nitrate in CWS wells near unlined water bodies, drainage ditches or water disposal ponds within one-half mile of the well. Similar results are obtained from analysis of individual factors as for the overall unlined water body factor presented in Exhibit 3-15. For instance, the presence of streams or rivers, unlined drainage ditches, natural lakes, man-made lakes, ponds, and bays or estuaries, within half mile of the well, are individually, as well as collectively, inversely associated with nitrate detections.

Of the irrigation methods included for analysis in the NPS, only flood irrigation shows an association with nitrate detections. Other types of irrigation and sources of water for irrigation within one-half mile of the well generally were not found to be associated with nitrate detections.

There is a lower chance of detecting nitrate in CWS wells with water treatment. The dominant factor for this relationship is use of water softeners, although there is evidence of an association with nitrate detections for all individual water treatments as well as for water treatments collectively.

Rural Domestic Well Survey Results

Exhibit 3-17 provides a summary of factors that analysis suggests are related to nitrate detections in rural domestic drinking water wells. Nitrate is different from pesticides with respect to its origins in ground and surface water. While pesticides always occur ultimately as a result of preceding human activity, and do not occur naturally, nitrate may be either anthropogenic in origin or naturally occurring. Natural forms of nitrate can be produced by certain algae, species of bacteria, and other organisms that have the capacity of photosynthesis. Nitrate also can occur in rainwater and may be of geologic origin. Detection of nitrate in well water, therefore, may not in all cases indicate contamination by anthropogenic sources. According to the U.S. Geological Survey, concentrations of nitrate can be classified as follows:

- "Less than 0.2 mg/L – Assumed to represent natural background concentrations.
- 0.21 to 3.0 mg/L – Transitional; concentrations that may or may not represent human influence.
- 3.1 to 10 mg/L – May indicate elevated concentrations resulting from human activities.
- More than 10 mg/L – Exceeds maximum concentration in National Interim Primary Drinking Water Regulations."[9]

Results are presented in this section for associations with both nitrate detections and concentrations.

Many questions were administered in the rural domestic well survey concerning farming and farming practices, such as pesticide use and storage and nitrogen fertilizer use. Of these, only use of the property where the well is located for pasture shows a relationship with nitrate detections. Use of non-farm pesticides on home lawns (Main B.2) and, more generally, use within one-half mile of the well (LAQ 5), are inversely related to nitrate detections.

Factors associated with well construction that were measured categorically did not, in general, show a relationship to nitrate detections. Use of a covered pit to protect the well surface was found to be associated with an increased chance of nitrate detections, that is, the result contradicted the hypothesis that there is a smaller chance of detecting nitrate in wells that have a covered pit to protect the well surface. The analysis provided evidence that the presence of other operating wells within 500 feet of the sampled well was directly related to nitrate detections. For the rural domestic well survey the quality of the water was also measured through responses to item A.10 of the Main Questionnaire. Analysis of this data indicates there may be a greater chance of detecting nitrate in wells in which the water is hard. There also may be a greater chance of detecting nitrate in wells that do not have water with color or odor.

Analysis of well depth and year of well construction showed evidence of a relationship with nitrate detections. Well depth information on the total distance from the ground surface to the bottom of the well was collected from question D.6 in the Main questionnaire. Analysis was performed to determine the extent of the relationship between well depth and nitrate detections and nitrate concentrations above 0.15 mg/L. Results of these analyses are presented in Exhibit 3-18. There is a clear relationship between nitrate detections and concentrations and well depth in the rural domestic wells, i.e., there is a greater chance of nitrate contamination in shallow wells and greater nitrate concentrations can be expected in shallow wells.

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[9] Madison, R.J. and J.O. Brunett, Overview of the Occurrences of Nitrates in Groundwater of the United States, National Water Summary 1984, U.S. Geological Survey Water Supply Paper #2275, 1985, p. 95; see also Power, J.F. and J.S. Schepers, Nitrate Contamination of Groundwater in North America, 26 (1989), Agriculture, Ecosystems and Environment, pp. 165-187. National Interim Primary Drinking Water Regulations became permanent Maximum Contaminant Levels following preparation of the 1984 U.S.G.S. paper.

Exhibit 3-17

Factors from NPS Questionnaires Associated with the Probability of Detecting Nitrate for Rural Domestic Wells

Factor (with Source Questionnaire and Item)	Direction of Effect	Significance Level (p-value)
Other operating wells within 500 feet. (Main B.12)	+	0.043
Covered pit protects the well at the surface. (WOR 3c)	+	0.015
Land used for pasture within one-half mile of the well since Jan 1, 1986.* (LAQ 3)	+	0.013
Pesticide retail outlet within one-half mile of the well. (LAQ 11n)	+	0.013
Unlined body of water within 300 feet of the well. (WOR 6b)	-	0.037
Grain elevator within one-half mile of the well. (LAQ 11o)	-	0.036
Ground water used for irrigation. (LAQ 15a)	-	0.033
Well water is hard (high iron or mineral content). (Main A.10c)	-	0.033
Unlined body of water within one-half mile of the well. (LAQ 12a, b, d, g, h, i, j, k, l)	-	0.015
Unlined drainage ditch within one-half mile of the well. (LAQ 12d)	-	0.0005
Water treatment applied to the water from the well. (TLI 2a, b, c, d, e, f)	-	0.0005

TLI = Team Leader Introduction
WOR = Well Observation Record
Main = Main Questionnaire
LAQ = Local Area Questionnaire

* For wells sampled after March 15, 1989, this question asked about pastures since January 1, 1987.

Exhibit 3-18

Models of the Relationship Between Nitrate Detections* and Concentrations and Well Depth and Year of Well Construction for Rural Domestic Wells

Dependent Variable	Explanatory Variable	Estimated Intercept	Standard Error	Estimated Explanatory Variable Coefficient (ℓn Scale)	Standard Error	Significance Level (p-value)
Nitrate Detection	ℓn(Well Depth)	2.646	0.616	–0.499	0.111	< 0.0005
ℓn(Nitrate Concentration)	ℓn(Well Depth)	2.617	0.489	–0.513	0.098	< 0.0005
Nitrate Detection	ℓn(Age)	–0.577	0.440	0.325	0.130	0.013

* Nitrate concentrations have been logarithmically transformed.

The average well depth for wells containing nitrate at concentrations above the minimum reporting limit is 144 feet for rural domestic wells, compared to an average depth of 213 feet for wells in which nitrate was not detected.

Information on the year in which sampled wells were constructed was collected from question D.3 in the rural domestic well Main questionnaire. As Exhibit 3-18 shows, there is some evidence of a relationship between nitrate detections and year of construction in the rural domestic well survey, but there is no evidence of a similar relationship for CWS wells.

Analysis of questions related to water bodies indicate that the presence of unlined water bodies or drainage ditches within one-half mile of rural domestic wells is negatively associated with nitrate detections. The result for unlined water bodies is largely influenced by the data for unlined drainage ditches. Nitrate detections in rural domestic wells are less likely if there are bodies of water present within 300 feet of the wells.

Irrigation and irrigation methods within one-half mile of the well were not found to be associated with nitrate detections. Analysis of the sources of water used for irrigation shows some evidence of a lower chance of detecting nitrate if groundwater near the well is used as an irrigation source.

The Local Area Questionnaire included items for many types of installations in the vicinity of the well. Of these, the data provide some evidence that there is a lower chance of detecting nitrate if a grain elevator is within one-half mile of the well. The data also provide some evidence that the presence of pesticide retail outlets within one-half mile of the well is directly related to nitrate detections.

Water treatment is found to be inversely correlated with nitrate detections in rural domestic wells. The dominant factor for this relationship is use of water softeners.

Summary of Nitrate Results

In general, there were an adequate number of nitrate detections to satisfy the statistical assumptions required for the procedures used. Exhibits 3-15 through 3-18 portray the results of analyses for which the descriptive significance level was less than 0.05. Of the many statistical analyses that were performed, these are the only ones for which preliminary conclusions can readily be made.

A few themes recur throughout the analysis:

- There is recurring evidence that nitrate is less likely to be detected if there are unlined bodies of water in the vicinity of the wells;
- Both the CWS and rural domestic well surveys indicate that there is a greater chance of nitrate detection in shallow wells and greater concentrations of nitrate can be expected in shallow wells; and
- Water treatment (after the point at which the wells were sampled) may be negatively associated with nitrate detections.

Another statistically significant factor concerns the generic type of aquifer from which CWS wells draw water:

- The CWS well survey indicates that there is a greater chance of nitrate detection from wells that draw water from unconfined aquifers.

3.4.2.2 Analysis of Pesticide Detections and Questionnaire Items

The Survey detected pesticides and pesticide degradates much less frequently than nitrate. Two analytes, DCPA acid metabolites (degradates of DCPA) and the pesticide atrazine, were the most frequently detected pesticide analytes in both CWS and rural domestic wells. Other analytes that were detected above minimum reporting limits in CWS wells include dibromochloropropane, dinoseb, hexachlorobenzene, prometon, and simazine. The rural domestic well survey also recorded detections of dibromochloropropane, prometon, simazine, EDB, lindane, ETU, bentazon, and alachlor. These results are reported in detail the NPS Phase I Report and summarized in Exhibits 1-1 and 1-2 in Chapter 1. This section presents the results of the analysis of relationships between detections of pesticides and pesticide degradates and well characteristics, local land features, and land uses on the property where the well is located or within one-half mile of the well. Extensive analysis of possible relationships among these factors was not possible because there were fewer detections of pesticides than nitrates.

The description of results follows the same pattern as those for the nitrate analysis presented in Section 3.5.2.1. Results are presented primarily for the detection of at least one pesticide or pesticide degradate, denoted by "any pesticide". There are two basic reasons for this approach. First, the NPS was designed to collect data on the presence of at least one pesticide or pesticide degradate rather than on any individual chemical. Second, generally there are too few detections of any single pesticide analyte to perform reasonable statistical analyses.

CWS Well Survey Results

Exhibit 3-19 provides a summary of factors that the analysis suggests are related to pesticide detections in CWS wells.

Exhibit 3-19

Factors from NPS Questionnaires Associated with the Probability of Detecting at Least One Pesticide or Pesticide Degradate for Community Water System Wells

Factor (with Source Questionnaire and Item)	Direction of Effect	Significance Level (p-value)
Other operating wells within 500 feet of the well. (Main A.35)	+	0.006
Use of well house or shed as protection at the well surface. (WOR 3a)	+	0.001
Unlined body of water within 300 feet of the well. (WOR 6b)	-	0.014

WOR = Well Observation Record
Main = Main Questionnaire
LAQ = Local Area Questionnaire

Questions related to farming practices and pesticide use and non-farm pesticide use did not provide evidence of a relationship with pesticide detections. Well construction characteristics did not show a relationship with pesticide detections in general; however, there is some evidence that use of a well house or shed and the presence of other operating wells within 300 feet of the sampled wells are associated with an increased likelihood of pesticide detections. Well depth apparently also is related to pesticide detections. Results for the relationship between pesticide detections and well depth are presented in Exhibit 3-20.

Exhibit 3-20

Logistic Regression Model for Well Depth for Community Water System Wells

Explanatory Variable	Estimated Intercept	Standard Error	Estimated Explanatory Variable Coefficient (ℓn Scale)	Standard Error	Significance Level (p-value)
ℓn(Well Depth)	0.603	0.938	–0.518	0.176	0.003

The average well depth in wells containing pesticides at concentrations above the minimum reporting limits is 230 feet in CWS wells, compared to an average depth of 385 feet for wells not containing at least one pesticide.

Analyses involving data collected about topography, soil type, and other land features within 300 feet of the well did not show evidence of a direct association with pesticide detections. Analyses of questions related to water bodies indicate that there is a lower likelihood of detecting pesticides in CWS wells if unlined bodies of water are within 300 feet of the well.

Irrigation, irrigation methods, and sources of irrigation water within one-half mile of the well were not found to be associated with pesticide detections, and there is no evidence of a relationship between water treatment and pesticide detections. There was also no evidence of a relationship between the presence of installations within one-half mile of CWS wells and pesticide detections.

Rural Domestic Well Survey Results

The rural domestic well survey recorded too few detections of pesticides and pesticide degradates to satisfy the assumptions underlying the procedures used for analyses. This problem was compounded by the small number of responses recorded for some possible answers to questionnaire items (i.e., the responses were very unbalanced). The problems caused by too few detections or small numbers of responses in some categories of answers can result in spurious or unreliable results. Chapter 2 provides a detailed explanation of the issues involved in determining appropriateness of the modeling procedure. Consequently, no result from the pesticide analysis in the rural domestic well survey is statistically significant when the statistical assumptions have been adequately satisfied and the conclusion agrees with the hypothesis of interest.

Summary of Pesticide Results

The three strongest associations of pesticide detections and questionnaire variables resulted from analysis of well depth for CWS wells, the use of a well house or shed to protect the well at the surface, and the presence of other operating wells in the vicinity of CWS wells, although the results for well house or shed protection at the surface do not support the intended hypothesis. Exhibits 3-18 and 3-19 portray results of analyses for which the statistical assumptions were adequately satisfied and for which descriptive significance level was less than 0.05. Of the many statistical analyses that were performed, these are the only ones for which preliminary conclusions can readily be made. There were, in many cases, too few pesticide detections to satisfy the statistical assumptions required for the procedures used. Although statistically significant results are not supported by similar results for other questionnaire items, this is partly due to the few detections or imbalance in the number of responses in different categories of the questions.

Responses to questions administered in the Second Stage County Agent Questionnaire were also analyzed for possible associations with pesticide detections in rural domestic wells. This questionnaire was administered to county agricultural extension agents prior to selecting rural domestic drinking water wells as part of the second stage stratification process. Though the information on local agricultural practices was considered to be more reliable than similar information gathered from questionnaires administered to homeowners, variables from this questionnaire also failed to provide evidence of associations with pesticide detections. Responses from this questionnaire were also analyzed for possible associations with nitrate detections, but there was no evidence to suggest relationships between questionnaire variables and detections.

3.4.3 Review of Pesticide Use Patterns

Information about particular pesticides used near sampled wells was gathered for both CWS and rural domestic wells[10]. These data were analyzed to determine if there was a relationship between reported pesticide use and pesticide detections. Based on the results of the analysis, there is insufficient evidence to suggest that pesticide use as reported on NPS questionnaires is associated with pesticide detections. Possible explanations for the lack of association include measurement error of the respondents, failure to fully capture data representing pesticide use in the recharge area of the well, and application of pesticides prior to the period for which information was obtained.

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[10] The CWS and rural domestic well questionnaires imposed different restrictions on the size of the local area and the number of years of use to be reported upon. For example, the Local Area Questionnaires required responses pertaining to an area within one-half mile of the sampled well and within three years prior to sampling, while the Main Questionnaire required responses for farm pesticide use on the property within the past five years.

Questionnaire responses about specific pesticide use generally provided brand names for pesticides. The brand names were matched with active ingredients from the NPS pesticides. Pesticide degradates, such as DCPA acid metabolites, were matched to their NPS pesticide active ingredients. Some chemicals could not be distinguished through the brand names supplied as responses to the questionnaire items. For example, chlordane could not be distinguished from the alpha and gamma chlordane isomers. NPS analytes designated as "qualitative only" were not included. One detected chemical, ETU, is a pesticide degradate that does not have a parent compound that was included in the NPS. Consequently, ETU is not included in the analyses reported in this section. Because ETU was detected very infrequently, it is unlikely that its exclusion has a significant impact on the analysis presented in this section. Full details of the 82 pesticide active ingredients (hereafter pesticides) included for analysis are provided in Exhibit 3-21.

Questions about both farm and non-farm pesticide use, storage, disposal, and spillage were analyzed from main and local area questionnaires from the CWS and rural domestic well surveys. Reported pesticide use information from the second stage county agent questionnaire also was analyzed.

Several approaches were taken to determine the extent of the relationship between pesticide use reported on NPS questionnaires and detections of pesticides. Exhibits 3-22 through 3-26 summarize reported pesticide use by pesticide detections, dividing them into four categories: (1) detected and reported as used; (2) detected and not reported as used; (3) not detected and reported as used; and (4) not detected and not reported as used.

Although these categories are mutually exclusive for individual well by pesticide observations, they are not mutually exclusive at the pesticide or well levels individually. For example, Exhibit 3-23 indicates that four pesticides were detected in and reported as used near rural domestic wells. This does not mean that every time these pesticides were detected they were reported as used. Instead, each of the four pesticides was reported as used in the vicinity of at least one well in which it was detected. The same four pesticides, however, could also appear in other categories. For example, atrazine falls into all four groups: atrazine was reported as used in some wells in which it was detected; it was not reported as used in other wells in which it was detected; it was reported as used in many wells in which it was not detected; and it was not reported as used in many wells in which it was not detected. At the pesticide level, observations (i.e., pesticides) are assigned to the first category into which they fell. For example, atrazine is included in the first group because it was reported as used in at least one well in which it was detected. Similarly, at the well level, wells are assigned to the first group into which they fall regardless of the possibility of use of multiple pesticides at a well site.

Analyses of reported pesticide use and detections of NPS pesticide active ingredients were performed at three levels:

1. Pesticide - The total number of observations is 82. Each observation corresponds to an NPS active ingredient and indicates to which of the above four groups a pesticide belongs;[11]

2. Well - The estimated percent of wells at which use of at least one NPS pesticide active ingredient at the well site was reported; and

3. Well by Chemical - Percents are provided that combine the previous two factors and correspond to estimated proportions of NPS wells nationally aggregated for each chemical.

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[11] NPS weights are not included in this analysis as weights correspond to wells rather than pesticides.

Exhibit 3-21

NPS Pesticide Active Ingredients Included in Analysis of Detections by Reported Pesticide Use

Alachlor
Aldicarb
Aldrin
Ametryn
Atraton
Atrazine
Barban
Baygon[a]
Bentazon
Bromacil
Butachlor
Butylate
Carbaryl
Carbofuran
Carboxin
Chlordane[b]
Chlorneb
Chlorothalonil
Chlorpropham
Cyanazine
Cycloate
DBCP
DCPA[c]
Dicamba
Dichlorprop
Dichlorvos
Dieldrin
Dinoseb
Diphenamid
Diuron
EDB
Endosulfan[d]
Endrin
EPTC
Ethoprop
Etridiazole
Fenamiphos
Fenamirol
Fluometuron
Fluridone
Heptachlor
Hexachlorobenzene
Hexazinone
Lindane[e]
Linuron
Methiocarb
Methomyl
Methoxychlor
Metolachlor
Metribuzin
Mevinphos
MGK-264
Molinate
Napropamide
Neburon
Norflurazon
Oxamyl
PCP
Pebulate
Permethrin[f]
Picloram
Prometon
Prometryn
Propachlor
Propanil
Propazine
Propham
Simazine
Simetryn
Stirofos[g]
SWEP
Terbuthiuron[h]
Terbutryn
Triademefon
Tricyclazole
Trifluralin
Vernolate
2,4-D
2,4-DB
2,4,5-T
2,4,5-TP
4,4-DDT

[a] Pesticide use information for Baygon was also collected under the name Propoxur.

[b] Chlordane data consists of chemical analysis of alpha and gamma chlordane isomers, and use of chlordane, alpha chlordane or gamma chlordane.

[c] DCPA data includes detections of its degradate DCPA acid metabolites. Use data for DCPA was also collected under the names Chlorthal-Dimethyl and Dacthal.

[d] Endosulfan data consists of chemical analysis of endosulfan I and II, and use of endosulfan, endosulfan I, or endosulfan II.

[e] Lindane data consists of chemical analysis of alpha, beta and gamma HCH, and use of Lindane, alpha HCH, beta HCH, or gamma HCH.

[f] Permethrin use data was collected under the names permethrin, cis-permethrin and trans-permethrin. Chemical analysis was performed on cis-permethrin and trans-permethrin.

[g] Stirofos use information was also collected under the name tetrachlovinphos.

[h] Terbuthiuron data was collected under the names Terbuthiuron, Tebuthiuron, and Terbacil. Chemical analysis was performed on Tebuthiuron and Terbacil.

The pesticide degradates ETU and methyl paraoxon were not included in the analysis. Parent compounds for these two chemicals degrade very rapidly and were not included in the list of NPS analytes.

Exhibit 3-22 shows that none of the seven pesticide active ingredients detected in CWS well samples are reported as used in the vicinity of the sampled CWS wells. Over half of the pesticide active ingredients included in this analysis were reported as used in the vicinity of CWS wells (Local Area Questionnaire q2). However, none of the 45 active ingredients reported as used within one half mile of CWS wells sites in the three years prior to sampling were detected in any sampled CWS well. In contrast, seven of the 37 NPS active ingredients not reported as used within one half mile of the well in the last three years were detected in at least one CWS well. These results are contrary to the expectation that the probability of detection in wells should be greater for pesticides that are used near those wells. Results for storage, disposal, and spillage of pesticides were inconclusive, because very few pesticides were reported as stored, disposed, or spilled in the vicinity of CWS well sites. No pesticides that were reported as stored, disposed, or spilled near CWS well sites were detected at those well sites.

Exhibit 3-22

Summary of Pesticide Detection by Reported Pesticide Use for Community Water System Wells: Pesticide Level

Questionnaire Item	Number of Pesticides Detected		Number of Pesticides Not Detected	
	Reported as Used	Not Reported as Used	Reported as Used	Not Reported as Used
Farm pesticide use in the past three years within one half-mile (LAQ q2).	0	7	45	30
Non-farm pesticide use on property in past three years (Main qB2)	0	7	8	67
Farm pesticide use on property in the past five years (Main qC3)	0	7	6	69

Results for rural domestic wells are similar to those for CWS wells. There is little evidence to suggest that reported pesticide use from NPS questionnaires is related to pesticide detections. Exhibit 3-23 shows that four of the nine pesticide active ingredients detected in rural domestic well samples were reported as used within one-half mile of at least one rural domestic well in the three years prior to sampling, and that approximately half of the NPS active ingredients included in this analysis were reported as used within one half mile of rural domestic wells in the three years prior to sampling. Results using responses from the second stage county agent questionnaire were very similar to those presented from the Local Area Questionnaire presented in Exhibit 3-23. Results for storage, disposal, and spillage of pesticides were inconclusive because very few pesticides were reported as stored, disposed, or spilled in the vicinity of rural domestic well well sites. No pesticides that were reported as stored, disposed, or spilled near rural domestic well sites were detected at those well sites.

Exhibit 3-23
Summary of Pesticide Detections by Reported Pesticide Use for Rural Domestic Wells: Pesticide Level

Questionnaire Item	Number of Pesticides Detected		Number of Pesticides Not Detected	
	Reported as Used	Not Reported as Used	Reported as Used	Not Reported as Used
Farm pesticide use in the past three years within one half-mile (LAQ q2)	4	5	37	36
Pesticide use on the lawn in the past three years (Main qB2)	0	9	5	68
Pesticide use on the garden in the past three years (Main qB3)	0	9	8	65
Farm pesticide use on crops on the property in the past five years (Main qC7)	3	6	27	46

The four pesticides that were detected and reported as used were alachlor, atrazine, bentazon, and DCPA[12]. The minimum reporting limits (MRLs) for these chemicals are 0.50, 0.12, 0.25, and 0.10[13] μg/L respectively. These MRLs are lower than the average MRLs for detected and non-detected pesticides which are 1.23 and 2.09 μg/L respectively (see Section 4.3.2.1)

Results presented at the pesticide level do not fully reflect the extent of the unexpected relationship between reported pesticide use and pesticide detections because a pesticide is categorized by the first category into which it falls. Although four pesticides detected in wells were reported as used near rural domestic wells, they may have been detected more than once, but may have been reported as used at comparatively few of the well sites at which they were detected. Analysis leading to the results presented in Exhibit 3-24 partially addresses this problem. Results are presented at the well, rather than the pesticide, level. The most noticeable difference between the results presented at the well level and the results presented at the pesticide level are those for rural domestic wells. Whereas four out of nine detected pesticides were reported as used (i.e., 44.4%), only 0.66% of the 4.14% estimated proportion of wells with detections (i.e., 15.9%) had reported use of the detected pesticides. The difference in these proportions (44.4% versus 15.9%) is a consequence of moving from a pesticide level analysis where pesticides were categorized in the first possible category to a well level analysis. The overall conclusion remains the same, i.e., that the reported pesticide use from NPS questionnaires and pesticide detections is not as expected.

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[12] DCPA acid metabolites, the pesticide degradate of DCPA, was the chemical actually detected in rural domestic wells.

[13] This is the MRL for DCPA acid metabolites, the degradate of DCPA that was detected in the NPS.

Exhibit 3-24

Summary by Pesticide Detection and Reported Pesticide Use from the Local Area Questionnaire: Well Level

	National Estimate of Proportion of Wells with Detections		National Estimate of Proportion of Wells with Non-Detections	
Survey	Reported as Used	Not Reported as Used	Reported as Used	Not Reported as Used
CWS	0%	10.01%	24.42%	65.58%
Rural Domestic	0.66%	3.48%	54.44%	41.42%

Even at the well level the four categories of detections by use are not mutually exclusive, i.e., often more than one pesticide is used at a well site, but a well by itself is used only as an indicator for all pesticides used at the well site. Although 0.66% of wells recorded detections of at least one pesticide that was reported as used, other pesticides, which were not detected, may also have been reported as used at that well site. Exhibit 3-25 shows the distribution of the number of pesticides used at CWS and rural domestic well sites according to Local Area Questionnaire responses[14]. The average number of pesticides reported as used at rural domestic well sites is 5.2, and at CWS well sites is 1.4, and the greatest number of pesticide active ingredients used at a CWS or rural domestic well site is 19.

A further analysis of reported pesticide use by pesticide detections was performed at the well by pesticide level. That is, each reported use of a pesticide near a well may be regarded as a "well-chemical" and represents the use and detection status for an individual chemical at a single well. Exhibit 3-26 shows the estimated proportion of detections by use across well-chemicals for both the CWS and rural domestic well surveys. The exhibit contains the same four groups as the above exhibits, but now each pesticide active ingredient is included in each of the four groups in proportion to the number of times it was reported in each use and detection category. The groups in Exhibit 3-26 are mutually exclusive across wells and pesticide active ingredients.

The results presented in Exhibit 3-26 confirm the earlier finding that reported pesticide use from NPS questionnaires is not related to pesticide detections. Of the 0.05% of well-chemicals that are estimated to occur above NPS minimum reporting limits in rural domestic drinking water wells, only 20% are estimated to be classified under "reported as used", whereas 80% are estimated to be classified under "not reported as used". This is contrary to initial expectations that detections would generally occur when pesticides are reported as used. The situation is more clear for CWS wells. None of the well-chemicals are both detected and reported as used.

Exhibit 3-26 also indicates the rarity of detecting an individual pesticide, and consequently helps explain why the NPS was not designed to measure and statistically analyze the presence of individual analytes. That is, the proportion of well-chemicals that are detected is 0.13% for CWS wells and 0.05% for rural domestic wells nationally.

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[14] The Local Area Questionnaire is used because there are substantially more reports of pesticide use from this questionnaire than from the Main Questionnaires.

Exhibit 3-25

Summary of the Number of Pesticide Active Ingredients Reported as Used from the Local Area Questionnaires by Number of Rural Domestic and Community Water System Wells Sampled

Number of Pesticide Active Ingredients Reported as Used	Number of Rural Domestic Wells Sampled	Number of CWS Wells Sampled
0	279	391
1	29	24
2	27	17
3	30	19
4	26	16
5	29	15
6	30	13
7	42	12
8	37	8
9	47	10
10	32	5
11	46	2
12	22	1
13	14	2
14	9	0
15	8	0
16	27	0
17	6	2
18	10	2
19	2	1

Exhibit 3-26

Summary by Pesticide Detection and Reported Pesticide Use from the Local Area Questionnaire: Well by Chemical Level

Survey	National Estimate of Proportion Detected		National Estimate of Proportion Not Detected	
	Reported as Used	Not Reported as Used	Reported as Used	Not Reported as Used
CWS	0%	0.13%	1.49%	98.38%
Rural Domestic	0.01%	0.04%	4.38%	95.57%

Note that the proportion of detected well-chemicals in rural domestic wells that are reported as used is approximately 20% (0.01% ÷ 0.05%), whereas the proportion of non-detected well-chemicals that are reported as used is approximately 4.4%. This implies that the probability of detecting a pesticide is greater if the pesticide is reported as used than if it is not reported as used. Due to the small number of detections a formal statistical test comparing these two proportions does not reveal a statistical difference. The corresponding proportions for CWS wells (i.e., 0% and 1.5%) do not allow concurrence with the conclusion for rural domestic wells.

The data used for the proportions presented in Exhibits 3-24 and 3-26 come from the Local Area Questionnaire items relating to farm pesticide use. The results indicate that, in general, pesticides were not reported as used and were not detected. There is insufficient data to be able to determine if there is a statistically significant relationship between reported pesticide use and pesticide detections, mainly because there are too few detections coupled with too few reports of pesticide use. However, the data suggest that reported pesticide use is not associated with pesticide detections, which is contrary to initital expectations. In particular, it is surprising to find that pesticides that were detected were most often not reported as used. Detections of NPS pesticides in sampled wells for which those pesticides are not reported as used could be explained by a number of factors, including the comparatively short period of time (up to five years) for which pesticide use information was obtained, the location of the recharge area with respect to the sampled wells, and measurement error in the responses.

3.5 Pesticide Use Data

This section reports results for analyses of associations between pesticide and nitrate detections and estimates of herbicide use for agricultural, urban and golf course purposes compiled by Resources for the Future, Inc. (RFF). The data have been gathered from a variety of sources including mail surveys conducted by RFF, national censuses, and national and state surveys.

The database on agricultural use of pesticides contains information on 96 active ingredients and 84 crops. This information was collected through a mail survey of Extension Service weed scientists, and was supplemented with other sources of state-specific herbicide use such as a 1984 survey of weed scientists conducted by the Agricultural Research Service, individual state surveys and reports, and published surveys for specific crops.[15] When information for states was not available from any of these sources, imputation was performed by assuming that the missing states's information is identical to that of a neighboring state.

The databases on urban and golf course use of pesticides were constructed using data from 1982 national surveys conducted by EPA's Office of Pesticide Programs. The urban applicators survey included three groups of applicators; tree, lawn, and structural. Further information used to construct the golf course database came from the 1980 Census of Housing and the National Golf Foundation.[16]

3.5.1 Pesticide Application for Agricultural Purposes

The agricultural pesticide use database was compiled at the state level for the 48 contiguous states. The data consist of the number of harvested acres in the state, the number of treated acres, and the quantity, measured in pounds of active ingredient, used within the state. Other factors are calculated from this information, such as the percent of harvested acres that are treated and the rate of application per treated acre. Harvested crop acreage for 84 crops was estimated from the 1987 Census of Agriculture.

RFF constructed a database at the county level from the state-level information by proportionately assigning the harvested acres of specific crops within a state according to the counties' relative sizes. Counties in which the crops are not grown were omitted from this process and were assigned a zero value. The procedure assumes the same rate of application of pesticides to individual crops throughout the state and assumes that all counties within a state have the same percent of individual crops grown (except for counties in which the crops are not grown). For example, atrazine is assumed to be applied to sorghum at a rate of two pounds per acre in all counties in Alabama that grow sorghum, and if sorghum is grown in 10 percent of the state then each county in that state is assumed to have 10 percent sorghum (adjusted for counties with no sorghum cropping).

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[15] Gianessi, L.P., and Puffer, C.A., The Use of Herbicides in the United States, Resources for the Future, Inc., Washington, D.C., paper presented at the National Research Conference, "Pesticides in the Next Decade: The Challenges Ahead," sponsored by Virginia Water Resources Research Center, Richmond, Virginia, November 9, 1990.

[16] Gianessi, L.P., and Puffer, C.A., Estimation of County Pesticide Use on Golf Courses and by Urban Applicators, Resources for the Future, Inc., Washington, D.C. report submitted to U.S. EPA, January 1991.

The analyses reported in this section use county-level information that is associated with the sampled wells by well location. Consequently, there are at least two levels of averaging of data that could affect the validity of the results. First, a well is associated with a county. Even though counties may have extensive pesticides use, the pesticides may not be applied near the sampled wells or the wells' recharge areas. Second, county-level information is constructed through state-level averaging in proportion to the counties' relative sizes. Large counties with minimal pesticide use or small counties with considerable pesticide use are not accounted for through the averaging process. Finally, measurement error associated with collection of the RFF data is not taken into account in the analyses presented in this section. Because NPS questionnaires were designed specifically to obtain information about pesticide use in the vicinity of the well, they should, given reliable responses, provide more locally precise measures of pesticide use at the well sites.

The analyses presented in this section use county-level data to assess relationships between pesticide use, measured through the RFF database, and pesticide detections. The measure of pesticide use required for analysis is the total pounds of pesticide applied per county acre. County size data are not available from the RFF database. To perform the analyses county size data were obtained from the County and City Data Book using 1986 data. The data were provided in units of square miles, and the appropriate multiplication was performed to transform land area in square miles to acres. Total pesticide use within a county was calculated by summing, for all crops, the rate of application measured in pounds per county acre.[17]

The only pesticide product that was detected sufficiently often for reasonable statistical analysis was DCPA acid metabolites. RFF data were available for DCPA, the parent compound. An analysis also was performed for aldicarb, which was not detected but is included in the RFF database, to compare rates of pesticide use in counties included in the NPS and counties not included in the NPS to help determine if the NPS sampled wells in comparatively high use areas.

The distributions of the rate of application variables for the different pesticides used in the analyses had many low application rates with a few cases of very high rates. A logarithmic transformation was used to obtain more symmetric distributions. This transformation was used for all regression models reported in this section.

Analysis of the relationship between agricultural DCPA use and detections of DCPA acid metabolites did not show sufficient evidence to suggest that the rate of DCPA use in agriculture (DCPA also has major non-agricultural uses) predicts DCPA acid metabolites detections. A similar analysis for the rural domestic well survey yielded qualitatively similar results, although this analysis may have been affected by the small number of DCPA acid metabolite detections in rural domestic wells. Selected means and standard errors are presented in Exhibit 3-27.

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[17] Pounds per county acre was determined by dividing the pounds of active ingredients variable from the RFF database by the county size. Given that county information in the RFF database is already prorated by county size and a rate of application variable is supplied, the need for a county size component is not immediately apparent. However, the rate of application variable supplied by RFF is assumed to be constant for a given state and crop. An individual pesticide is generally applied at different rates for different crops, hence the need for county size to provide a more appropriate measure of rate of total pesticide use throughout the county.

Exhibit 3-27

Summary Statistics for Rate of DCPA Use in Agricultural Areas

Survey	Status	Mean Rate of Use (lbs/acre)	Standard Error	Mean Logarithm of Rate of Use	Standard Error
CWS	Detected	0.011	0.005	-6.72	0.62
	Non-Detected	0.006	0.001	-7.81	0.22
Rural Domestic	Detected	0.002	0.001	-7.58	0.53
	Non-Detected	0.002	< 0.0005	-8.42	0.34

Further analyses were considered to determine whether or not selected NPS chemicals are used more heavily in counties included in the NPS study than in other counties. This analysis could shed light on possible explanations for the pattern of which pesticides were detected by the survey. For example, NPS did not detect aldicarb, yet data from other sources such as EPA's Pesticide in Groundwater Database indicate that in certain areas, contamination of drinking water wells by aldicarb is of concern. The RFF database provides information that could be used to indicate if the NPS sampled in comparatively high pesticide use counties.

Before completion of this analysis, the data in the RFF database was compared to information from the manufacturer to ensure that the distribution of pesticide sales is accurately represented by the RFF database. For one chemical with relatively lower sales, this comparison uncovered significant differences between the RFF database and the manufacturer's data. For one chemical with relatively higher sales, the publicly available data adequately represented the confidential data held by the manufacturer.

In particular, the Phase II analysis found significant differences between the manufacturer's confidential database and the publicly accessible data on aldicarb in the RFF database. The targeting of areas of aldicarb use was evaluated using confidential sales distribution data supplied by the registrant of aldicarb. These data are counties' totals of aldicarb, (in pounds of active ingredient) sold to distributors in 1988. The data indicate that 6 of the 90 counties included in the rural domestic well survey and 80 of he 299 counties included in the CWS well survey have aldicarb distribution. In contrast, data from RFF indicate that 66 of the 90 counties in the rural domestic well survey and 267 of the 399 counties in the CWS survey have aldicarb use. Similar differences between RFF data and manufacturer's data were also found for alachlor in a review of the NAWWS data. These differences may be due to several factors: Distribution points within counties may provide aldicarb to adjacent counties, and the RFF database is constructed, in part, by assuming that counties have aldicarb use if crops for which aldicarb is recommenced are grown.

The pesticide sales distribution data for the relatively high volume chemical atrazine in the RFF database appears to match the manufacturer's data fairly well.

Because of the uneven reliability of information in the public domain on the distribution of pesticides within states, the NPS analysis could not determine whether the counties sampled by NPS were nationally representative of the use of individual pesticides.

3.5.2 Pesticide Applications in Urban Areas

EPA's Office of Pesticide Programs commissioned a national survey of urban commercial tree, lawn, and structural pest control applicators in 1982. The survey reports the aggregate use within each EPA Region of ten selected active ingredients by urban pesticide applicators. A further component of the RFF urban applicators database consists of estimates of the number of single family housing units taken from the 1980 Census of Housing.[18]

To construct a county-level database, the aggregate use estimate for each active ingredient for each EPA Region was divided by the single family housing unit estimate for the region to provide a rate of application measured in units of pounds of active ingredient per housing unit. These estimates were then prorated to counties in proportion to the number of housing units in the county. This procedure uses averaging on a greater scale than is used to construct the RFF county agricultural database (since there are 10 EPA Regions nationally compared to 48 contiguous states).

Analysis at the well level involves associating a well with a county by well location. The variable required for analysis measures the total pesticide use by urban applicators within a county, adjusted by the county size.

DCPA, the parent compound of the DCPA acid metabolites detected in the Survey, was the only pesticide contained in the RFF urban applicators database that recorded sufficient detections in the NPS for reasonable analysis. A logarithmic transformation of the DCPA use data was used in the analyses because the distribution of the use data was heavily skewed. Exhibit 3-28 provides details of the estimated models of the relationship between the logarithm of DCPA use and the probability of detecting DCPA acid metabolites.

Exhibit 3-28

Estimated Models of the Relationship Between DCPA Acid Metabolites Detections and DCPA Use by Urban Application

Survey	Independent Variable	Intercept Estimate	Standard Error	Beta Coefficient Estimate	Standard Error	Significance Level (p-value)
CWS	ℓn(Rate of DCPA Use) (pounds per county acre)	2.213	1.086	0.729	0.180	< 0.0005

Exhibit 3-29 provides summary statistics of DCPA use in both CWS and rural domestic wells. These exhibits present strong evidence of a positive relationship between the rate of DCPA use for urban application and the probability of detecting DCPA acid metabolites in both CWS and rural domestic wells.

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[18] Gianessi, L.P., and Puffer, C.A., The Use of Herbicides in the United States, Resources for the Future, Inc., Washington, D.C.

Exhibit 3-29

Summary Statistics for Rate of DCPA Use by Urban Application

Survey	Wells in Which DCPA was Detected or Not Detected	Mean Rate of Use (lbs/acre)	Standard Error	Mean Logarithm of Rate of Use	Standard Error
CWS	Detected	0.010	0.002	-5.67	0.39
	Non-Detected	0.002	< 0.0005	-8.02	0.12
Rural Domestic	Detected	0.005	0.001	-5.86	0.33
	Non-Detected	0.002	< 0.0005	-7.49	0.17

3.5.3 Pesticide Applications on Golf Courses

Data pertaining to use of selected pesticide active ingredients on golf courses was obtained by RFF from a national survey commissioned by EPA's Office of Pesticide Programs in 1982. This survey reports the aggregate use of pesticides on golf courses by EPA Region. Information about golf courses in each state was compiled from the Statistical Profile of Golf in the United States published by the National Golf Foundation. An assumption of 7.9 acres per golf hole was used to estimate the number of golf courses acres within a state.[19]

To construct a county-level database the aggregated use estimate was first divided by the golf course acreage estimate for each EPA Region. County-level estimates were then created by prorating the EPA Region totals to counties in proportion to county golf course acreage. The variable required for analysis measures the total pesticide use on golf courses within a county, adjusted by the county size. Analysis was carried out by associating NPS wells with counties by well location.

DCPA, the parent compound of the DCPA acid metabolites detected in the Survey, was the only pesticide that is contained in the RFF golf course database that recorded sufficient detections in the NPS for reasonable analysis. A logarithmic transformation of the DCPA use data was used in the analyses because the distribution of the use data was strongly skewed. Exhibit 3-30 provides details of the estimated models of the relationship between the logarithm of the rate of DCPA use and the probability of detecting DCPA acid metabolites. Exhibit 3-31 provides summary statistics of DCPA use in both CWS and rural domestic wells. These exhibits present strong evidence of a positive relationship between the rate of DCPA use on golf courses and the probability of detecting DCPA acid metabolites in both CWS and rural domestic wells.

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[19] Gianessi, L.P., and Puffer, C.A., Estimation of County Pesticide Use on Golf Courses and by Urban Applicators, Resources for the Future, Inc., Washington, D.C.

Exhibit 3-30

Estimated Model of the Relationship Between DCPA Acid Metabolites Detections and DCPA Use on Golf Courses

Survey	Independent Variable	Intercept Estimate	Standard Error	Beta Coefficient Estimate	Significant Error	Significance Level (p-value)
CWS	ℓn(Rate of DCPA Use) (pounds per county acre)	0.817	0.685	0.590	0.126	< 0.0005

Exhibit 3-31

Summary Statistics for Rate of DCPA Use on Golf Courses

Survey	Wells In Which DCPA was Detected or Not Detected	Mean Rate of Use (lbs/acre)	Standard Error	Mean Logarithm of Rate of Use	Standard Error
CWS	Detected	0.018	0.005	-5.04	0.31
	Non-Detected	0.005	0.001	-6.85	0.10
Rural Domestic	Detected	0.014	0.005	-5.04	0.43
	Non-Detected	0.004	0.001	-6.54	0.16

3.6 Fertilizer Sales Data

This section describes studies of the relationship between nitrate and pesticide detections and county-level data on nitrogen fertilizer sales, agricultural crop production and animal stock levels obtained by EPA (the NFERC/EPA Fertilizer Sales Data).[20] The data cover the six "fertilizer years" between July 1, 1984 and June 30, 1990. Each "fertilizer year" corresponds to the period over which nutrients are most commonly applied in the production of a crop. These data were prepared at the Division of Resources Management at West Virginia University in conjunction with the National Fertilizer and Environmental Research Center (NFERC) at the Tennessee Valley Authority in Alabama. The Fertilizer Sales Data are maintained as two separate databases. The first concerns nitrogen fertilizer sales; the second concerns agricultural crop production and livestock production. The data were used to test the hypotheses that higher occurrences of nitrate and pesticide detections occur in areas with high nitrogen sales, high levels of crop production, and/or high levels of livestock production.

3.6.1 Nitrogen Fertilizer Sales

The analyses reported in this section use estimated county-level nitrogen fertilizer sales information that is associated with the sampled wells by well location. The county-level information was constructed through state-level averaging in proportion to the counties' relative expenditures on fertilizers. That is, expenditures are used as a surrogate for sales. The measure of fertilizer sales required for analysis is the total tons of nitrogen fertilizer sales per county acre. County sizes are not available from the NFERC database. To perform the analyses, data on the number of acres in each county were obtained from the County and City Data Book using 1986 data.[21] These data were provided in units of square miles, and the appropriate multiplication was performed to transform land area in square miles to acres.

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[20] County-Level Fertilizer Sales Data. United States Environmental Protection Agency, Policy Planning and Evaluation (PM-221), September 1990.

The NFERC data reflect total sales of fertilizer without regard to where or when the fertilizer is used. Sales figures can only be a proxy for use. Also, fertilizer may be bought in one county and used in another; similarly, it may be purchased in one season and used in a subsequent season. Although manure is a significant contributor to fertilizer use, it is not measured with the NFERC data. Finally, even though counties may have large nitrogen fertilizer sales, the fertilizer may not be applied near the sampled wells or their recharge areas.

The agricultural crop production and animal stock levels database (see next section) uses 1987 Census of Agriculture data. Consequently, 1987 nitrogen fertilizer sales data were used for consistency of analysis. This has the added advantage of using data that precedes the NPS survey, so that analysis of the NPS and NFERC data is not confounded by the time of well sampling. The annual NFERC data are, however, highly correlated across years. Correlation coefficients for total nitrogen fertilizer sales exceed 0.99 for all pairs of annual variables. Correlations across years for the six groups of nitrogen fertilizer were also high. Consequently, use of 1987 annual nitrogen fertilizer sales data is likely to produce qualitatively similar results to data from other years. Similarly, correlations between annual and fall sales data were very high (usually exceeding 0.9).

Seven NFERC variables (logarithmically transformed) were ultimately evaluated for correlation with NPS pesticide or nitrate detections, and nitrate concentrations: 1987 nitrogen fertilizer sales data for all six nitrogen fertilizer groups (ammonium nitrate, anhydrous ammonia, miscellaneous forms, nitrogen in solution, urea, and total nitrogen), and commercial fertilizer use, measured in acres on which used, from the 1987 Census of Agriculture. These variables were adjusted for county size.

None of the analyses by nitrate detections provided evidence of a relationship between NFERC variables and the probability of nitrate detections. Nitrate concentrations (logarithmically transformed), however, were found to be positively related to all the NFERC variables. Exhibit 3-32 presents results for total nitrogen fertilizer sales for both the CWS and rural domestic well surveys. Tons of nitrogen sold per county acre was found to be associated with nitrate concentrations for both CWS and rural domestic wells. The remaining NFERC variables are highly correlated with total nitrogen fertilizer sales, and provide qualitatively similar results.

One NFERC variable provided evidence of a relationship with pesticide detections in each of the CWS and rural domestic well surveys. For the CWS well survey this variable was ammonium nitrate sales per county acre (p-value = 0.010), but the effect is in the opposite direction to that expected. For the rural domestic well survey, the significant predictor variable corresponded to miscellaneous nitrogen fertilizer sales per acre (p-value = 0.012). The overall case for a relationship between pesticide detections and nitrogen fertilizer sales is weak, since only one of fourteen analyses yielded a significant result in the direction of the hypothesis, and the NFERC variables are highly correlated.

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[21] U.S. Department of Commerce, Bureau of the Census. County and City Data Book, 1988. All areas are defined as of October 18, 1986.

Exhibit 3-32

Estimated Models for the Relationship of Nitrate Concentrations* By Total Tons of Nitrogen Sold per County Acre

Survey	Estimated Intercept	Standard Error	Estimated Independent Variable ln(Tons/Acre)	Standard Error	Tons/Acre Coefficient Significance Level (p-value)
CWS	-0.832	0.214	0.144	0.029	< 0.0005
Rural Domestic	-1.526	0.572	0.261	0.084	0.002

* Nitrate concentrations are logarithmically transformed.

In summary, there is strong evidence of a relationship between nitrate concentrations and nitrogen fertilizer sales data. This relationship is not supported by analyses of nitrate detections. Although nitrate detections offer a comparison of nitrate contamination above and below the NPS minimum reporting limit of 0.15 mg/L, rather than a continuous measure above 0.15 mg/L, the results for these two sets of analyses should be expected to be qualitatively similar. The overall evidence to support a relationship between pesticide use and nitrogen fertilizer sales per county acre is too weak to be used to provide predictive models.

3.6.2 Agricultural Crop Production and Livestock Production

The second part of the NFERC/EPA database consists of county-level information gathered from the 1987 Census of Agriculture. The data are organized into three categories: general crop acreage and crop and livestock value; specific crop acreage and crop production; and animal counts.[22]

Though more than 50 variables are available from the Census of Agriculture data, many of these variables are highly correlated. The variables fall into five main categories:

- Crop farming;
- Fertilizer use on cropland;
- Livestock production;
- Fertilizer use on range or pasture land; and
- Miscellaneous variables (such as vegetable and orchard farming).

Five variables (logarithmically transformed) were chosen for analysis:

CROPVAL - Market value of crops, including greenhouses and market gardens in $1,000;

CROPFERT - Acres of cropland fertilized, excluding range and pastureland;

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[22] The crops reported in the database include corn for seed and silage, soybeans, wheat, barley, oats, sorghum, cotton, beans, rice, sunflower, vegetables, sugar beets, potatoes, peanuts, sugar cane, hay, and tobacco. Combined orchards and vegetable acreage variables are also available. Animal inventories are included for livestock consisting of chicken, beef and milk cows, sheep, horses, and hogs.

PASTFERT - Acres of range and pastureland fertilized;

LVSTVAL - Market value of livestock in $1,000; and

BEEFCOW - Number of beefcows.

Several variables were highly correlated and yielded qualitatively similar predictive capabilities. CROPVAL, for example, was highly correlated with other total measures of crop farming such as harvested cropland and market value of agricultural products, and with commonly grown crops such as corn, wheat, soybeans, and hay. Three variables related to fertilizer use on crop farming land were highly correlated. Variables related to animal farming, including the total live stock value and variables measuring the number of milk cows, horses, hogs, chickens, and sheep were all positively correlated. The BEEFCOW variables, however, was found to be negatively correlated with the other animal farming variables. The livestock value variable (LVSTKVAL) was also found to be correlated with crop farming variables.

Exhibits 3-33 and 3-34 present results of analyses of the relationship between the five Census of Agriculture variables and detections in wells. Exhibit 3-35 presents results of analysis of the relationship between Census of Agriculture variables and nitrate concentrations.

Exhibit 3-33

Estimated Models for Selected Census of Agriculture Variables by Nitrate Detections

Survey	Independent Variable	Estimated Intercept	Standard Error	Estimated Independent Variable Coefficient	Standard Error	Descriptive Significance Level (p-value)
CWS	BEEFCOW	0.51	0.15	-20.51	6.77	0.003
CWS	LVSTKVAL	-0.07	0.12	2.14	0.92	0.020
CWS	PASTFERT	0.32	0.13	-26.31	7.82	0.001

Exhibit 3-34

Estimated Models for Selected Census of Agriculture Variables by Pesticide Detections

Survey	Independent Variable	Estimated Intercept	Standard Error	Estimated Independent Variable Coefficient	Standard Error	Descriptive Significance Level (p-value)
CWS	PASTFERT	-1.74	0.21	-74.12	27.50	0.007
CWS	BEEFCOW	-1.59	0.26	-41.98	18.11	0.021
Rural Domestic	CROPVAL	-1.14	0.60	0.58	0.19	0.002
Rural Domestic	BEEFCOW	-5.63	1.29	-0.50	0.25	0.043

Exhibit 3-35

Estimated Models for Selected Census of Agriculture Variables by Nitrate Concentrations Above 0.15 mg/L*

Survey	Independent Variable	Estimated Intercept	Standard Error	Estimated Independent Variable Coefficient	Standard Error	Descriptive Significance Level (p-value)
CWS	CROPVAL	0.06	0.09	3.14	0.74	< 0.0005
CWS	CROPFERT	-0.06	0.10	2.67	0.56	< 0.0005
CWS	LVSTKVAL	0.10	0.09	2.03	0.50	< 0.0005
Rural Domestic	CROPVAL	1.40	0.29	0.27	0.06	< 0.0005
Rural Domestic	CROPFERT	1.06	0.31	0.26	0.09	0.005
Rural Domestic	LVSTKVAL	1.15	0.40	0.23	0.10	0.022

* Nitrate concentrations are logarithmically transformed.

In general, crop farming variables are positively associated with nitrate concentrations, though there is insufficient evidence to support a similar hypothesis of a relationship with nitrate detections. There is some evidence of a relationship between crop farming variables and pesticide detections in rural domestic wells, but that evidence is not supported in CWS wells or by results for other crop farming variables. Fertilizer use on crop land is associated with nitrate concentrations for CWS wells and rural domestic wells.

Analysis of other variables that measure vegetable and orchard farming indicate positive correlations with nitrate concentrations. These results are in line with results for crop farming variables.

Animal inventory variables fall into two categories. The market value of livestock variable provides qualitatively similar results to the crop farming variables, whereas the beef cow variable yields opposite effects. Analysis of the fertilizer use on range and pasture land variable yields similar results to those for the beef cow data. That is, fertilizer use on range and pasture land is negatively associated with pesticide and nitrate detections.

3.7 Well Water Characteristics: Temperature, pH, and Conductivity

This section presents results of the analyses of the association of detections with well water temperature, pH, or electrical conductivity (measured as the concentration of total dissolved solids) as potential indicators of the presence of pesticides or nitrate in well water. Two hypotheses were tested: (1) that pesticide persistence, and thus the likelihood of detection, increases at lower temperatures and low pH conditions; and (2) that nitrate persistence, and thus the likelihood of detection, increases at lower temperatures and in both low and high pH conditions.

Results are presented first for CWS wells and second for rural domestic wells. Logistic regression models were developed to examine the relationship of water temperature, pH, and conductivity of pesticide and nitrate detections. The statistical analyses for electrical conductivity involved a logarithmic transformation of the conductivity data. Although the estimated coefficients of the regression models are included, their interpretation must account for the transformation of the conductivity data.

A data set consisting of the initial, stabilized, and final readings of well water temperature, pH, and conductivity was derived from the records of well purging conducted at the time of sampling. These were used as indicators of the availability of fresh ground water for sampling. The instruments used for these measurements were calibrated frequently to minimize calibration errors. However, the well purging data set was not subject to the same level of scrutiny, on the basis of established quality assurance procedures, as most of the NPS data. The initial, stabilized, and final readings were compared and aggregated to derive the data used for analysis. The stabilized reading was treated as the primary reading for analysis.[23]

3.7.1 Well Water Characteristics for CWS Wells

The results for CWS wells presented in Exhibits 3-36 to 3-38 indicate that both pesticide and nitrate detections in CWS wells are negatively associated with well water temperature and pH levels. The pesticide results were presented for "any pesticide" rather than any smaller group of pesticides because there were too few detections in the smaller groups to satisfy the statistical assumptions of the analysis, though the results were qualitatively similar to those for any pesticide group. Consistent with the prior hypotheses, these findings imply that:

Exhibit 3-36

Association of Detections with Well Water Temperature for Community Water System Wells

Analyte Detection Group	Estimated Intercept	Standard Error	Estimated Temperature Coefficient	Standard Error	Temperature Coefficient Significance Level (p-value)
Any Pesticide	−0.466	0.458	−0.113	0.030	< 0.0005
Nitrate	0.824	0.312	−0.047	0.018	0.010

* Based on logistic regression model of detections.

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[23] Measured well water temperatures ranged from a low of 1 degree celsius to a high of 37 degrees celsius, with a mean temperature of approximately 17 degrees. Well water pH ranged from 4.7 to 9.6 with a mean of approximately 7.4. Conductivity values ranged from 0 to 2500 ppm Total Dissolved Solids (TDS) with a mean of approximately 230 ppm TDS. Data were treated as missing when the three readings were too disparate or when the readings suggested nonsensical results (e.g., one reading of a pH of 0.8 was reported). The statistical results reflect those data ranges, and may not be appropriate for data outside those ranges.

Exhibit 3-37

Association of Detections with Well Water pH for Community Water System Wells

Analyte Detection Group	Estimated Intercept	Standard Error	Estimated pH Coefficient	Standard Error	pH Coefficient Significance Level (p-value)
Any Pesticide	0.504	0.888	–0.359	0.120	0.003
Nitrate	2.994	1.216	–0.392	0.161	0.015

* Based on logistic regression model of detections.

- the probability of detecting at least one pesticide or nitrate is greater in wells with low water temperature; and
- the probability of detecting at least one pesticide or nitrate is greater in wells with low water pH (i.e., high acidity).

Conductivity was not found to be associated with pesticide detections, but was found to be associated with nitrate detections. That is, the probability of detecting nitrate is greater in wells with low electrical conductivity. In contrast, however, analysis of nitrate concentration analysis of nitrate concentrations showed that higher electrical conductivity corresponds to greater concentrations. These results are presented in Exhibit 3-38.

Exhibit 3-38

Association of Detections of Nitrate and Nitrate Concentrations with Well Water Conductivity* for Community Water System Wells

Dependent Variable	Estimated Intercept	Standard Error	Estimated ℓn(Conductivity) Coefficient	Standard Error	ℓn(Conductivity) Coefficient Significance Level (p-value)
Nitrate	2.083	0.635	–0.401	0.122	0.001
ℓn(Nitrate concentrations)	–1.103	0.390	0.274	0.081	0.001

* Well water electrical conductivity and nitrate concentrations are logarithmically transformed.

3.7.2 Well Water Characteristics for Rural Domestic Wells

The results for rural domestic wells presented in Exhibit 3-39 indicate that nitrate detections in rural domestic wells are negatively associated with pH levels. Results for temperature and conductivity for rural domestic wells were qualitatively similar to results for CWS wells (see Appendix A) but did not satisfy the 0.05 significance criterion. The significant findings imply that the probability of detecting nitrate is greater in wells with low water pH (i.e., high acidity).

Exhibit 3-39

Association of Well Water pH* with Detections of Nitrate for Rural Domestic Wells

Analyte Detection Group	Estimated Intercept	Standard Error	Estimated pH Coefficient	Standard Error	pH Coefficient Significance Level (p-value)
Nitrate	7.964	1.551	-1.043	0.204	< 0.0005

* Well water pH has been logistically transformed.

In summary, detection of pesticides and nitrate in drinking water wells are found to be related to some characteristics of well water. These relationships are generally stronger for the CWS well survey than for the rural domestic well survey, though the results are generally in the same direction. Results from both surveys indicate negative correlations of well water temperature, pH, and conductivity with the probability of pesticide and nitrate detections in wells. However, the results suggest that there is a positive correlation between conductivity and nitrate concentration.

3.8 Pesticide Chemical Characteristics

This section reports the results of an examination of the relationship between pesticide detections and soil half-life or soil adsorption partition coefficients. Statistical analyses were conducted to determine if pesticide detections could be related to the soil half-life or soil adsorption coefficient (organic carbon coefficient or K_{oc}).

Degradation half-life is defined as the time required for half the concentration of a chemical to degrade. The principal mechanism of degradation of pesticides in soil is microbial degradation. The process of photolysis (degradation in sunlight) and hydrolysis (degradation in water) also can be important for certain pesticides in certain conditions. The rate of degradation for a pesticide is not only an inherent characteristic, it is also very dependent on site-specific conditions. Higher soil temperatures and moisture are more conducive to microbial degradation; exposure to sunlight is critical to photolysis. The NPS Phase II analysis could not account for such site-specific conditions.

The organic carbon partition coefficient K_{oc} characterizes the mobility of pesticides in soils. It is defined as the ratio of the concentration of pesticide sorbed to organic carbon in soil divided by the concentration in solution at equilibrium. It is a property known for most pesticides and is generated in laboratory conditions.[24] The mobility of a pesticide is not only an inherent property, it is also a function of site-specific conditions. The higher the K_{oc} the more strongly adsorbed the pesticide is to soil, organic matter, and sediment. Pesticides were originally selected to be included in the Survey based in part on sorption and degradation properties.[25]

Both soil half-life and K_{oc} information is available for 64 of the 126 pesticides included in the NPS. Soil half-life information alone is available for one more pesticide, as is K_{oc} information alone.

Three statistical analyses were performed to study the relationship between soil half-life, K_{oc}, and detected chemicals.

- Exploratory analyses, including means, standard errors, stem and leaf plots, and box plots;
- Analysis of variance or t-tests to determine if detected pesticides differed from nondetected pesticides in terms of soil half-life or K_{oc}; and
- Logistic regression to determine if soil half-life or K_{oc} predicted detected chemicals.

The data for these analyses pertain only to those pesticides for which soil half-life or K_{oc} data are readily available. For each study, these pesticides were divided into two groups corresponding to pesticides that were detected or not detected in the Survey. The statistical analyses were performed on the 65 soil half-life and the 65 K_{oc} observations, not NPS samples of wells. The variable of interest is "detection of pesticide in the NPS" rather than "detection of pesticide in a well." Accordingly, the analysis does not rely on the NPS design and was performed unweighted.

Because the variable of interest is pesticides detected in the NPS, data were collapsed across both the CWS and rural domestic well survey. The mean soil half-life and mean K_{oc} and the standard errors of the two groups of pesticides (detected and not detected) are provided in Exhibit 3-40. This exhibit also includes the means and their standard errors for the logarithmically transformed data. Exploratory analysis of both the soil half-life and K_{oc} data indicated that the distributions are heavily skewed to the right. Accordingly, results of t-test and logistic regression analyses results are provided only for the transformed data.

Unlike most analyses presented in other sections of this report, analyses involving half-life and K_{oc} are necessarily chemical-specific rather than well-specific. The NPS was designed to investigate the presence of pesticides and nitrate in wells, and the survey was designed to control for potential confounding factors. Analyses of half-life and K_{oc} were not the focus of the NPS and consequently are subject to possible uncontrolled confounding factors. Two factors in particular -- individual pesticide use and detection limits -- may affect the conclusions concerning whether soil half-life or K_{oc} differ for the two analyte groups. If an active ingredient was not used in the location of any wells in the NPS, then that analyte would not have been detected, and if the analyte is present at concentrations that are less than the minimum reporting limit (MRL) it would not have been detected. Atrazine and DCPA acid metabolites were the most commonly detected pesticide and pesticide degradate in the NPS, but both are known to be widely used, and their MRLs were relatively low. Other active ingredients, such as Bromacil, are not widely used, or their MRLs are relatively high, so regardless of their soil half-life or K_{oc} they still are unlikely to have been detected. Statistically significant results presented in this Section should be regarded as preliminary when considering whether they are applicable beyond the NPS study.

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[24] The K_{oc} is calculated by measuring the ratio of sorbed to solution pesticides concentrations after equilibrium of a pesticide in a water/soil slurry, and then dividing by the weight fraction of organic carbon present in the soil.

[25] See Chapter 4.0 of the NPS Phase I Report for more information on analyte selection.

Exhibit 3-40

Means and Standard Errors of Soil Half-Life and K_{oc} for Detected Analytes and Non-Detected Analytes

		Soil half-life	ℓn(half-life)	K_{oc}	ℓn(K_{oc})
Detected Analytes[a]	Mean	220	4.4	1,340	4.5
	Standard Error	86	0.5	1,160	0.7
Nondetected Analytes[b]	Mean	54	3.4	6,730	5.7
	Standard Error	10	0.2	3,500	0.3

[a] For two analytes in this group the soil half-life was provided as a range. The lowest value of the ranges was used to provide maximum conservatism (least significance) in the testing and regression procedures. For two analytes in this group the K_{oc} was provided as a range. The lowest value of the range was used to provide the most significant results for K_{oc}.

[b] For one analyte in this group the soil half-life was provided as a range. The highest value of the range was used to provide maximum conservatism in the testing and regression procedures. Also for two analytes in this group the K_{oc} was provided as a range. The highest value of the ranges was used to provide the most significant results for K_{oc}.

Pesticides for which quantification of the concentration detected was not possible are not included in the analyses presented in this section. The Phase I Report provides a complete listing of pesticides included in the NPS, including whether or not concentrations of the pesticides were quantifiable.

For each study, the pesticides were divided into two groups corresponding to pesticides that were detected and pesticides that were not detected in the Survey. For both soil half-life and K_{oc} there are 12 chemicals in the former group and 53 in the latter group.

The t-test provides a measure of the differences between the two groups of analytes in terms of soil half-life and K_{oc}. A summary of the results is provided in Exhibit 3-41. Soil half-life tends to be higher for detected analytes than for nondetected analytes (as indicated by the descriptive significance level or p-value of 0.02), whereas K_{oc} is not significantly different for the two groups of chemicals (p-value = 0.22).

Exhibit 3-41

Soil Half-Life and K_{oc} Effects for Detected Analytes and Non-Detected Analytes

	ℓn(half-life)	ℓn(K_{oc})
t-statistic	2.51	1.68
p-value	0.01	0.10

The list of chemicals used in these analyses and their corresponding soil half-life and K_{oc} values are presented in Exhibit 3-42 for detected NPS chemicals and Exhibit 3-43 for non-detected chemicals. Other sources may provide different values but values used here are expected to be representative for the chemicals listed.

Exhibit 3-42

Soil Half-Life and K_{oc} for Detected Pesticides

Detected Pesticide	Soil Half-Life (Days)	K_{oc}
Alachlor	15	170
Atrazine	60	70
Bentazon	20	21-34
DCPA and acid metabolites[a]	365	4-90
Dibromochloropropane (DCBP)	180	129
Dinoseb	20	124
Ethylene Dibromide (EDB)	28-180	1
Ethylene thiourea (ETU)	7	50
Hexachlorobenzene	990-2080	14100
Lindane[b]	400	1081
Prometon	500	200
Simazine	80	103

a The minimum soil half-life for DCPA acid metabolites is 365 days.

b The NPS detected both gamma-HCH and beta-HCH. However, soil half-life and K_{oc} information is available for Lindane only, without distinguishing between gamma-HCH and beta-HCH.

c Nitrate is not included in this table or in the reported analysis because it is not an organic compound. Nitrate has a K_{oc} of zero and no half-life value.

Exhibit 3-43

Soil Half-Life and K_{oc} for Pesticides that Were Not Detected

Detected Pesticide	Soil Half-Life (Days)	K_{oc}
Aldicarb	30	30
Aldicarb Sulfone	20	10
Ametryn	60	300
Butylate	13	400
Carbaryl	10	300
Carbofuran	50	22
Carboxin	7	260
Chlordane[a]	N/A	140000
Chlorneb	130	1650
Chlorothalonil	30	1380
Chlorpropham	30	400
Cyanazine	14	190
Cycloate	30	430
2,4-D	10	20-100
2,4-DB	7-10	20-500
DCPA	100	NA
Dicamba	14	2
cis-1,3-dichloropropene	10	32
Diphenamid	30	210
Diuron	90	480
Endosulfan	50	12400
EPTC	6	200
Ethoprop	25	70
Etridiazole	20	1000
Fenamiphos	50	100
Fenarimol	360	600
Fluometuron	85	100
Fluridone	21	1000
Hexazinone	90	54
Linuron	60	400

[a] Although chlordane is comprised of alpha-chlordane and gamma-chlordane, K_{oc} information is available for chlordane only.

Exhibit 3-43 (continued)

Soil Half-Life and K_{oc} for Pesticides that Were Not Detected

Detected Pesticide	Soil Half-Life (Days)	K_{oc}
Methiocarb	30	300
Methomyl	30	72
Methoxychlor	120	80000
Metolachlor	90	200
Metribuzin	40	60
Mevinphos	3	44
Molinate	21	190
Napropamide	70	400
Norflurazon	90	600
Oxamyl	4	25
Pebulate	14	430
Permethrin	30	100000
Prometryn	60	400
Propachlor	6.3	80
Propanil	1	149
Propazine	135	154
Propham	10	200
2,4,5-T	24	80
Tebuthiuron	360	80
Terbacil	120	55
Terbutryn	42	2000
Triademefon	21	300
Trifluralin	60	8000
Vernolate	12	260

Source: Wauchope, R. Don, Selected Values for Six Parameters from the SCS/ARS/CES Pesticide Properties Database: A Brief Description, February 20, 1991 and selected values prepared for the U.S. EPA Environmental Criteria and Assessment Office as revisions to the Superfund Public Health Evaluation Manual, 1986.

The logistic regression analyses consider the extent to which soil half-life or K_{oc} can be regarded as predictors of the probability of detection of an analyte in the NPS, and should be expected to give qualitatively the same results as the t-tests presented above. Exhibit 3-44 provides details of the estimated coefficients for the logistic regression models for ℓn(half-life) and $\ell n(K_{oc})$.

Exhibit 3-44

Models of the Relationship Between Pesticides Detected and Half-life or K_{oc} in the NPS

Explanatory Variable	Estimated Intercept	Standard Error	Estimated Explanatory Variable Coefficient - ℓn Scale	Standard Error	Significance Level (p-value)
ℓn(Half-life)	−3.96	1.19	+0.64	0.28	0.021
$\ell n(K_{oc})$	−0.01	0.95	−0.29	0.18	0.100

The results of the logistic regression indicate that there is a relationship between soil half-life and the probability of a pesticide's detection in at least one well in the NPS, but there is no evidence of a similar relationship for K_{oc}.

An additive model involving both soil half-life and K_{oc} as independent variables showed strong evidence for a positive relationship between soil half-life and the probability of detecting a pesticide (p-value = 0.008), and weak evidence of a relationship for K_{oc} (p-value = 0.034).[26] This model provides a marginally better fit for the data than the model involving half-life only. A further model including an interaction term for half-life and K_{oc} does not provide a better fit. Some of the half-life and K_{oc} data were provided as a range because the sources used to compile the data provided differing values. The results presented in this section are based on analyses that use extreme values from these ranges. This corresponds to the least possible significance for half-life and the most possible significance for K_{oc}. If the opposite assumption is made, the results for K_{oc} in the additive model yield a descriptive significance levels greater than 0.1, providing further evidence that the best model based on NPS data contains a half-life term only.

The soil half-lifes for detected pesticides were higher those for the nondetected pesticides. The soil half-life values used for the detected pesticides ranged from 7 to 990 days. The soil half-life values for the nondetected pesticides ranged from 3 to 360 days. As Exhibit 3-44 and the subsequent statistical analyses demonstrate, the means of the soil half life values for detected and not detected pesticides differ significantly. This finding can be interpreted as providing evidence that pesticides that persist longer in the environment are more likely to be detected in drinking water wells. However, these analyses are subject to the influence of the small number of detections and other uncontrolled confounding effects and are applicable to the range of the data only (that is the range of half-life values and, more importantly, the chemicals used in this analysis). Extrapolation to other groups of chemicals should be treated with caution. Similar evidence for a relationship between pesticide detections and K_{oc} was not found.

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[26] Chlordane has the highest K_{oc} value used in the analyses presented above. Chlordane was not detected at concentrations above the NPS minimum reporting levels for α-chlordane and γ-chlordane of 0.060 μg/L. Both isomers of chlordane were detected at much lower levels by the EPA laboratories. If chlordane is treated as a detected chemical instead of a non-detected chemical in the analyses reported in this section, the p-value for K_{oc} in the univariate logistic regression model changes from 0.100 to 0.480. A similar comparison can not be made for the additive model since a half-life for chlordane was not specified. An increase in p-value, or decrease in significance, could be expected.

3.9 Relationship Between Nitrate Detections and Concentrations and Pesticide Detections

This section provides the results of an analysis of the extent of the association between nitrate and pesticide detections in drinking water wells. The underlying hypothesis for these analyses is that pesticide detections in drinking water wells follows the same pattern as nitrate detections. Results of the analysis of the relationship between pesticide detections and nitrate detections are presented first, followed by results of the analysis of pesticide detections with nitrate concentration given nitrate detection above the NPS minimum reporting limit of 0.15 mg/L. Analysis of the relationship between nitrate and pesticide concentrations is not feasible as there are insufficient detections for any single pesticide and the pesticides generally have different NPS minimum reporting limits.

The results of the analysis of nitrate and pesticide detections presented in Exhibit 3-45 provide weak evidence that there is a greater chance of at least one pesticide detection when nitrate is detected. Results are presented in this section rather than in Appendix A even though the p-values exceed 0.05 to enable discussion of the topic to be included. The effects are not strong enough to fully substantiate a hypothesis of association between nitrate and pesticide detections but are mildly suggestive. The weakness of the result may be due to the small number of pesticide detections that are distributed among four categories for this analysis. Analysis of smaller groups of pesticides leads to the same type of results when there are sufficient data to satisfy the underlying statistical assumptions required.

Exhibit 3-45

Analysis of Association between Nitrate and Pesticide Detections

Survey	Proportion of Pesticide Detections When Nitrate		Significance Level (p-value)
	Detected	Not Detected	
CWS Wells	12.8 percent	7.4 percent	0.093
Rural Domestic Wells	5.6 percent	2.4 percent	0.061

Results of the analysis relating nitrate concentrations and pesticide detections are presented in Exhibit 3-46. These results do not substantiate the results presented above, i.e., there is insufficient evidence to suggest that pesticide detections are related to nitrate concentrations. These results are based on a logistic regression analysis with the logarithm of nitrate concentration as the independent variable, and the logistic function of the probability of pesticide detection as the dependent variable. The models are not useful for predictive purposes due to the comparatively large p-values for the estimated independent variable coefficients. Analysis of smaller groups of pesticides leads to the same type of results when there is sufficient data to satisfy the underlying statistical assumptions required.

Exhibit 3-46

Analysis of Association Between Nitrate Concentration and Pesticide Detections

Survey	Estimated Intercept	Standard Error	Estimated Coefficient for ℓn(Nitrate)	Standard Error	Significance Level (p-value)
CWS Wells	-2.26	0.24	0.24	0.20	0.225
Rural Domestic Wells	-3.20	0.31	0.14	0.13	0.292

In summary, there is insufficient evidence to suggest a relationship between nitrate concentration and pesticide detections, and weak support for an association between nitrate and pesticide detections. These results alone do not provide sufficient evidence to support a hypothesis of a correlation between nitrate and pesticide contamination in drinking water wells nationally.

3.10 Precipitation and Drought

This section presents the results obtained from analyses of the relationship between pesticide and nitrate detections and two measures of precipitation: (1) data on precipitation patterns and (2) an index of drought conditions.

In order to assess the impact of precipitation patterns on the occurrences of pesticides and nitrate in well water, NPS obtained precipitation data from weather stations across the U.S. for 405 counties with CWS wells (399 counties in which wells were sampled and 6 counties contiguous to counties in which wells were sampled but for which precipitation data were unavailable) and 90 counties in which rural domestic water wells were sampled. A new set of variables depicting short-term and long-term precipitation characteristics, based on the sampling date (i.e., month and year), were then extracted from the monthly precipitation data set. These variables are:

- Quantity of precipitation during the month of well sampling (PCUR);
- Quantity of precipitation during the month prior to sampling (PPREV);
- Average monthly precipitation for the year prior to sampling (PAVG1);
- Maximum monthly precipitation for the year prior to sampling (PMAX1);
- Average monthly precipitation for the two years prior to sampling (PAVG2);
- Maximum monthly precipitation for the two years prior to sampling (PMAX2);
- Average monthly precipitation for the five years prior to sampling (PAVG5); and
- Maximum monthly precipitation for the five years prior to sampling (PMAX5).

In order to determine if the 1988-1989 drought in the central and western United States had an impact on the Survey detection estimates, NPS obtained information on drought severity from the Climate Analysis Center of the National Oceanic and Atmospheric Administration (NOAA/CAC). These data were based on the Drought Severity Index or Palmer Drought Index (PDI). The PDI was developed by Palmer in 1965 to evaluate meteorological drought. PDI is currently being used jointly by NOAA and the United States

Department of Agriculture (USDA) to depict prolonged abnormal dryness or wetness on a regional scale across the United States[27].

A data set consisting of well-specific drought severity and moist spell categories was then extracted from the "Drought Severity Index by Division" maps generated by NOAA/CAC. In these maps, categories of drought and moist spell are defined as:

Extreme drought:	PDI less than or equal to -4.0;
Severe drought:	PDI from -3.0 to -3.9;
Moderate drought:	PDI from -2.0 to -2.9;
Near normal:	PDI from -1.9 to 1.9;
Unusually moist:	PDI from 2.0 to 2.9;
Very moist:	PDI from 3.0 to 3.9; and
Extremely moist:	PDI greater or equal to 4.0.

3.10.1 Results of Analysis of Precipitation Data

Community Water System Wells. This section describes results of the analyses performed to examine the relationship between precipitation and pesticide and nitrate detections and nitrate concentrations in CWS well water. Analyses for wells with pesticide and nitrate detections were examined for evidence of associations between precipitation variables and detections. The results for pesticides and nitrate detections are summarized in Exhibits 3-47 and 3-48 respectively. Herbicide detections and DCPA acid metabolites detections yield qualitatively similar results to those presented for pesticide detections. Smaller subgroups of pesticides do not contain sufficient detections to satisfy the statistical assumptions.

Exhibit 3-47

Estimated Models of the Probability of Pesticide Detections by Precipitation Factors for Community Water System Wells

Precipitation Variable	Estimated Intercept	Standard Error	Estimated Precipitation Variable Coefficient	Standard Error	Significance Level (p-value)
Maximum monthly 2 years prior	-1.495	0.377	-0.093	0.043	0.032

Based on results of the analyses presented in Exhibit 3-47, the probability of detecting pesticides in CWS wells is not generally related to precipitation factors. There is some evidence of exceptions for the occurrence of intense precipitation events over an extended period as indicated by the results for precipitation variable PMAX2. The precipitation variables are, however, highly correlated.

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[27] Palmer, Wayne C., Meteorological Drought, U.S. Department of Commerce, Weather Bureau, Research Paper No. 45, Washington, D.C., February, 1965. The Palmer Drought Index (PDI) is calculated for each climatic division designated by NOAA. The number of climatic divisions per State ranges from 2 to 10 with a mode of 8.

Exhibit 3-48

Estimated Models of the Probability of Nitrate Detections by Precipitation Factors for Community Water System Wells

Precipitation Variable	Estimated Intercept	Standard Error	Estimated Precipitation Variable Coefficient	Standard Error	Significance Level (p-value)
During month of sampling	0.526	0.163	−0.160	0.040	< 0.0005
During prior month	0.431	0.171	−0.136	0.047	0.004
Monthly average for 1 year prior	1.463	0.286	−0.495	0.094	< 0.0005
Monthly average for 2 years prior	1.763	0.311	−0.589	0.101	< 0.0005
Monthly average for 5 years prior	2.210	0.361	−0.700	0.111	< 0.0005
Monthly maximum for 1 year prior	1.141	0.258	−0.156	0.034	< 0.0005
Monthly maximum for 2 years prior	1.446	0.291	−0.166	0.034	< 0.0005
Monthly maximum for 5 years prior	1.841	0.342	−0.171	0.032	< 0.0005

Analysis of the relationship between precipitation factors and nitrate concentrations in CWS wells yields results that substantiate those for nitrate detections. Results of the concentration-based analyses are presented in Exhibit 3-49. With the exception of the previous month precipitation factor, all precipitation factors exhibit a negative correlation with nitrate concentration. The results presented are for models for the logarithmic transformation of nitrate concentration.

Rural Domestic Wells. This section describes results of the analyses performed to examine the relationship between precipitation and pesticide and nitrate detections and nitrate concentrations in rural domestic well water. The results for nitrate detections are summarized in Exhibit 3-50. Smaller subgroups of pesticides do not contain sufficient detections to satisfy the statistical assumptions necessary for correlation or regression analysis.

Based on results of these analyses, the probability of detecting pesticides or nitrate is not generally related to precipitation factors. There is some evidence of an exception for the relationship between nitrate detections and intense precipitation events during the previous five years, as indicated by the results for the precipitation variable PMAX5 (see Exhibit 3-50). The precipitation variables are, however, highly correlated.

Analysis of the relationship between precipitation factors and nitrate concentrations in rural domestic wells is presented in Exhibit 3-51.

Exhibit 3-49

Estimated Models of Nitrate Concentration* by Precipitation Factors for Community Water System Wells

Precipitation Variable	Estimated Intercept	Standard Error	Estimated Precipitation Variable Coefficient	Standard Error	Significance Level (p-value)
During month of sampling	0.450	0.116	–0.083	0.034	0.015
Monthly average for prior year	0.672	0.175	–0.161	0.062	0.010
Monthly average for prior 2 years	0.729	0.88	–0.198	0.066	0.003
Monthly average for prior 5 years	0.749	0.200	–0.194	0.068	0.004
Monthly maximum for prior year	0.667	0.172	–0.072	0.025	0.005
Monthly maximum for prior 2 years	0.825	0.189	–0.082	0.024	0.001
Monthly maximum for prior 5 years	0.787	0.223	–0.060	0.022	0.008

* Nitrate concentrations are logarithmically transformed.

Exhibit 3-50

Estimated Models of the Probability of Nitrate Detections by Precipitation Factors for Rural Domestic Wells

Precipitation Variable	Estimated Intercept	Standard Error	Estimated Precipitation Variable Coefficient	Standard Error	Significance Level (p-value)
Monthly maximum for 5 years prior	1.873	0.584	–0.156	0.055	0.005

Exhibit 3-51

Estimated Models of Nitrate Concentration* by Precipitation Factors for Rural Domestic Wells

Precipitation Variable	Estimated Intercept	Standard Error	Estimated Precipitation Variable Coefficient	Standard Error	Significance Level (p-value)
Monthly average for prior year	0.831	0.305	–0.140	0.067	0.040

* Nitrate concentrations are logarithmically transformed.

3.10.2 Palmer Drought Index

Community Water System Wells. Results of statistical analyses involving the Palmer Drought Index are presented first for pesticide detections, next for nitrate detections, and finally for nitrate concentrations. A frequency distribution for wells with pesticide detections was examined for evidence of an association between drought conditions and the detection of any pesticide in CWS well water. The distribution of wells with pesticide detections across various drought and moist spell categories is presented in Exhibit 3-52.

Exhibit 3-52

Frequency Distribution of Estimated Pesticide Detections by Drought and Moist Spell Categories for Community Water System Wells

Drought and Moist Categories	Estimated Number of Wells with Pesticide Detections	Estimated Total Number of Wells	Estimated Percent of Wells with Pesticide Detections
Extreme Drought	1,140	8,080	14.1
Severe Drought	180	5,980	3.0
Moderate Drought	1,300	13,200	9.8
Near Normal Condition	6,000	55,100	10.9
Unusually Moist	190	6,410	3.0
Very Moist	570	4,590	12.4
Extremely Moist	0	1,200	0

No observable trend relates the proportion of wells with pesticide detections to drought or moist conditions measured by the PDI. The apparent fluctuations are a function of the relatively small number of wells estimated to contain detectable levels of pesticides for some of the PDI categories. There are too few pesticide detections to be spread across the seven PDI categories in a statistical analysis. To determine if there is sufficient evidence of a drought effect on pesticide detections the seven categories were collapsed into three categories signifying drought, normal, and moist conditions. As shown in Exhibit 3-49, when drought and moist conditions are collapsed the percents of pesticide detections by drought categories become very similar. A statistical analysis of the differences between the three mean proportions presented in Exhibit 3-53 indicates there is insufficient evidence to suggest drought conditions are related to pesticide detections.

Exhibit 3-53

Frequency Distribution of Estimated Pesticide Detections by Collapsed Drought and Moist Spell Categories for Community Water System Wells

Drought and Moist Categories		Estimated Number of Wells with Pesticide Detections	Estimated Total Number of Wells	Estimated Percent of Wells with Pesticide Detections
Drought	(PDI less than or equal -2)	2,610	27,300	9.6
Near Normal	(PDI from -1.9 to 1.9)	6,000	55,100	11.4
Moist	(PDI greater than or equal 2)	770	12,200	6.3

A frequency distribution for wells with nitrate detections was also examined for evidence of an association between drought conditions and the detection of nitrate in CWS well water. The distribution of wells with nitrate detections is presented in Exhibit 3-54.

Exhibit 3-54

Frequency Distribution of Estimated Nitrate Detections by Drought and Moist Spell Categories for Community Water System Wells

Drought and Moist Categories	Estimated Number of Wells Nationally with Nitrate Detections	Estimated Total Number of Wells Nationally	Estimated Percent of Wells Nationally with Nitrate Detections
Extreme Drought	5,160	8,080	64
Severe Drought	3,680	5,980	62
Moderate Drought	6,440	13,200	49
Near Normal Condition	28,700	55,100	52
Unusually Moist	1,910	6,410	30
Very Moist	2,430	4,590	53
Extremely Moist	710	1,200	59

The percent of wells with nitrate detections appears to be greater in drought areas than in moist areas. To determine if there is sufficient evidence of a drought effect on nitrate detections the seven categories were collapsed into three categories signifying drought, normal, and moist conditions. As shown in Exhibit 3-55, when drought and moist conditions are collapsed the difference in percents of nitrate detections by drought categories becomes more apparent. However, a statistical analysis of the differences between the three mean proportions presented in Exhibit 3-55 does not yield a statistically significant result, i.e., there is no evidence based on this analysis to suggest drought conditions are related to nitrate detections in CWS wells.

Exhibit 3-55

Frequency Distribution of Estimated Nitrate Detections by Collapsed Drought and Moist Categories for Community Water System Wells

Drought and Moist Categories		Estimated Number of Wells Nationally with Nitrate Detections	Estimated Total Number of Wells Nationally	Estimated Percent of Wells Nationally with Nitrate Detections
Drought	(PDI less than or equal to -2)	15,300	27,300	56
Near Normal	(PDI from -1.9 to 1.9)	28,700	55,100	52
Moist	(PDI greater than or equal to 2)	5,050	12,200	41

A further analysis was performed to determine the relationship between nitrate concentrations and the three collapsed categories of PDI (drought, normal, and moist). The average nitrate concentrations for these drought categories are presented in Exhibit 3-56. Statistical analyses were performed on the logarithm of nitrate concentrations that correctly account for the standard errors of the mean values. Analysis of the differences in means of the logarithm of nitrate concentrations yields a descriptive significance level of 0.003, providing strong evidence that nitrate concentrations are lower in CWS wells in moist regions.

Exhibit 3-56

Means of Nitrate Concentrations For Collapsed Drought and Moist Categories for Community Water System Wells

Drought and Moist Categories		Mean Nitrate Concentration (mg/L)	Mean ℓn(Nitrate Concentration)
Drought	(PDI less than or equal to -2)	2.51	0.34
Near Normal	(PDI from -1.9 to 1.9)	2.49	0.33
Moist	(PDI greater than or equal to 2)	1.13	-0.44

Rural Domestic Wells. A frequency distribution for wells with pesticide detections was examined for evidence of an association between drought conditions and the detection of any pesticide in rural domestic well water. The distribution of wells with pesticide detections across various drought and moist spell categories is presented in Exhibit 3-57.

Exhibit 3-57

Frequency Distribution of Estimated Pesticide Detections by Drought and Moist Spell Categories for Rural Domestic Wells

Drought and Moist Spell Categories	Estimated Number of Wells with Pesticide Detections	Estimated Total Number of Wells	Estimated Percent of Wells with Pesticide Detections
Extreme Drought	18,700	415,000	4.5
Severe Drought	38,400	956,000	4.0
Moderate Drought	23,800	719,000	3.3
Near Normal	234,000	4,860,000	4.8
Unusually Moist	81,400	1,500,000	5.4
Very Moist	29,100	1,150,000	2.5
Extremely Moist	0	907,000	0

The occurrences of pesticides in rural domestic well water do not appear to be related to the presence of drought or moist spells. The estimated percents of wells with pesticide detections for various drought or moist spell categories (Exhibit 3-57) are not associated with any observable trend. There is no increase or decrease in the percents of detected pesticides with changes in moisture conditions. In addition, when the three drought categories and the three moist categories are collapsed into two categories, the estimated percents of pesticide detections by drought categories are very similar (Exhibit 3-58). It appears unlikely that the presence of drought had any influence on the occurrence of pesticides in rural domestic well water.

Exhibit 3-58

Frequency Distribution of Pesticide Detections by Collapsed Drought and Moist Spell Categories for Rural Domestic Wells

Drought and Moist Spell Categories		Estimated Number of Wells with Pesticide Detections	Estimated Total Number of Wells	Estimated Percent of Wells with Pesticide Detections
Drought	(PDI less than or equal -2)	80,900	2,090,000	3.9
Near Normal	(PDI from -1.9 to 1.9)	234,000	4,860,000	4.8
Moist	(PDI greater than or equal 2)	110,000	3,560,000	3.1

A frequency distribution for wells with nitrate detections was also examined for evidence of an association between drought conditions and the detection of nitrate in rural domestic well water. The distribution of wells with nitrate detections is presented in Exhibit 3-59.

Exhibit 3-59

Frequency Distribution of Estimated Nitrate Detections by Drought and Moist Spell Categories for Rural Domestic Wells

Drought and Moist Spell Categories	Estimated Number of Wells Nationally with Nitrate Detections	Estimated Total Number of Wells Nationally	Estimated Percent of Wells Nationally with Nitrate Detections
Extreme Drought	230,000	415,000	56
Severe Drought	589,000	956,000	62
Moderate Drought	516,000	719,000	72
Near Normal	2,510,000	4,860,000	52
Unusually Moist	772,000	1,500,000	51
Very Moist	741,000	1,150,000	65
Extremely Moist	620,000	907,000	68

The percent of wells with nitrate detections does not appear to differ significantly across PDI categories. To verify that there is insufficient evidence of a drought effect on nitrate detections the seven categories were collapsed into three categories signifying drought, normal, and moist conditions. A statistical analysis of the differences between the three mean proportions presented in Exhibit 3-60 shows that there is insufficient evidence (p-value > 0.1) that drought conditions are related to nitrate detections in rural domestic wells.

Exhibit 3-60

Frequency Distribution of Estimated Nitrate Detections by Collapsed Drought and Moist Categories for Rural Domestic Wells

Drought and Moist Categories		Estimated Number of Wells Nationally with Nitrate Detections	Estimated Total Number of Wells Nationally	Estimated Percent of Wells Nationally with Nitrate Detections
Drought	(PDI less than or equal to -2)	1,340,000	2,090,000	57
Normal	(PDI from -1.9 to 1.9)	2,510,000	4,860,000	51
Moist	(PDI greater than or equal to 2)	2,130,000	3,560,000	60

A further analysis was performed to determine the relationship between nitrate concentrations and the three collapsed categories of PDI (drought, normal, and moist). The average nitrate concentrations for these drought categories are presented in Exhibit 3-61. Statistical analyses were performed on the logarithm of nitrate concentrations that correctly account for the standard errors of the mean values. Analysis of the differences in means of the logarithm of nitrate concentrations shows no evidence that nitrate concentrations are lower in rural domestic wells in moist regions p-value > 0.5).

Exhibit 3-61

Means of Nitrate Concentrations for Collapsed Drought and Moist Categories for Community Water System Wells

Drought and Moist Categories		Mean Nitrate Concentration (mg/L)	Mean ℓn(Nitrate Concentration)
Drought	(PDI less than or equal to -2)	3.72	0.35
Near Normal	(PDI from -1.9 to 1.9)	3.17	0.36
Moist	(PDI greater than or equal to 2)	2.54	0.29

Pesticide and nitrate detections in rural domestic wells are not found to be related to drought conditions measured through the Palmer Drought Index. Though the lack of a relationship with pesticide detections can possibly be attributed in part to the small number of detections, the same cannot be said for nitrate detections. The results for rural domestic wells do not corroborate the results for CWS wells, suggesting that the effect of drought conditions nationally is different for CWS wells than for rural domestic wells.

Chapter Four: Evaluation of Results

In designing the National Pesticide Survey, EPA sought to develop information on five major factors that affect the presence of pesticides and nitrate in ground water -- ground-water sensitivity, agricultural activity and pesticide and fertilizer use, contaminant transport mechanisms, chemical properties of pesticides, and physical characteristics of wells. EPA collected data on these key factors using a number of different variables and measurement levels. For both CWS wells and rural domestic wells, the data can be viewed as describing three successive zones surrounding the sampled wells: the area near the well on the well owner's property (ranging from 300 to 500 feet, depending on the information sought); the area within one-half mile of the well; and the area within the county where the well is located. Data were also collected for rural domestic wells for a fourth zone, sub-county "cropped and vulnerable" areas surrounding the well.

Chapter 3 describes the results of more than one thousand data analysis tests carried out to identify variables that are associated with nitrate and pesticide detections in the NPS. EPA's objective in conducting these analyses was to improve its understanding of the relationship of ground-water sensitivity, fertilizer and pesticide use, transport, chemical properties of pesticides, and physical characteristics of wells to pesticide and nitrate detections. EPA sought to identify strong evidence to develop indicators of vulnerable wells, in order to support several objectives. The Phase II results may be used both to guide program and policy, as support for the implementation of the EPA Pesticide in Ground Water Strategy, data for assessment of pesticide registration and review, information to support improvements in the control of nitrate pollution sources, and to identify additional research needs.

This chapter evaluates the results of the Phase II analysis presented in Chapter 3 from several different standpoints. First, EPA regrouped the significant results in terms of the five key factors and sought to identify trends in each group, as well as conflicting or inconsistent results. Possible trends were then evaluated with respect to the quality of the data upon which they were based, and compared to results obtained by other surveys and studies of similar topics. Next, EPA conducted multivariate analyses using combinations of results to test models composed of the major findings as potential indicators of contamination. Third, EPA assessed the potential effects of factors that could limit or confound the identification of significant variables.

The purpose of this chapter is, in part, to present an explicit discussion of the quality of the individual results. Chapter 3 stated the hypotheses tested and identified whether the results are considered to support or contradict the hypothesis. This chapter evaluates those supporting or contradictory results in the following ways:

- By assessing the amount and quality of data upon which the result is based;
- By providing additional details concerning why the result was evaluated as supporting or not supporting particular hypotheses; and
- By comparing the results to the results of other selected recent surveys and studies of ground-water contamination by pesticides and nitrate.

Much of the background necessary for assessing the amount and quality of data supporting particular results is provided in the NPS Phase I Report. In particular, the Phase I Report provides important background on the planning and background of the Survey, including choice of analytes, development of multi-residue analytic methods, choice of stratification variables, and well sampling and data collection techniques. Copies of the questionnaires used in the Survey and national estimates, including confidence limits, for many of the questionnaire items are provided in Appendix D of that report.

An overall comparison of the key results of the NPS and of selected surveys of the presence of pesticides and nitrate in ground water or well water are presented in Exhibit 4-1. The survey most closely resembling the NPS is the National Alachlor Well Water Survey (NAWWS), which was a statistically-based survey based on a design similar to the NPS that sought to estimate the proportion of private, rural domestic wells with detectable concentrations of alachlor, four other herbicides, and nitrate, located in counties nationwide in which alachlor is sold.[1]

Four other surveys also are included, out of the large number of state and local ground water studies that have been conducted, because of their scope and the period of time in which they were carried out. They are the Iowa State-Wide Rural Well-Water Survey; the Wisconsin Grade A Dairy Farm Well Water Survey; the Rhode Island Private Well Water Survey; and the Minnesota Surveys of Selected Minnesota Wells. These surveys were selected for comparison to the National Pesticide Survey because they were carried out at approximately the same time as the NPS, each involved sampling of private rural wells (although several surveys sampled other categories of wells in addition), and each analyzed water samples for selected pesticides and nitrate.[2] These other surveys were generally limited in scope to a single state or portion of a state. They are not probability-based, but chose special geographic areas, such as karst regions, or areas associated with selected activities, such as dairy farming, for sampling. Several carried out extensive sampling, and some used repeat sampling of the same well or location. Like the NPS, most analyzed samples using multiresidue chemical analytic methods, sometimes accompanied by single tests for specific analytes. The NPS analyzed for the largest number of analytes.

As Exhibit 4-1 indicates, all of these surveys detected nitrate in about half of the wells sampled. The proportions of wells containing at least one pesticide varied more widely among surveys, from a low of 4.2 percent for the NPS rural domestic well survey to a high of 51 percent for the Minnesota Department of Agriculture study. Differences in detection rates could be due to several factors, including random versus targetted sampling, different reporting limits, and absence of mass spectrometry confirmation.

Comparison of the results for the NPS community water system well survey with the results for the NPS rural domestic well survey provide some inconclusive evidence that CWS wells may be more vulnerable to contamination than rural domestic wells. In general, pesticides, including atrazine and DCPA acid metabolites, were detected more frequently in CWS wells than in rural domestic wells. However, the concentrations of pesticides were generally lower in CWS wells than in rural domestic wells. The highest concentrations found in rural domestic wells were substantially higher than the highest concentrations of the same pesticide found in CWS wells. The highest concentrations of DCPA acid metabolites, in contrast, were found in CWS wells.

The Phase II analyses were not able to identify factors that were associated with these differences between CWS wells and rural domestic wells. Three possible factors were considered, but the Phase II analysis could not conclusively identify significant results relating to them. First, the possibility of greater drawdown by large CWS wells could be associated with the presence of larger numbers of analytes at lower concentrations. Insufficient data on system sizes and well pumping rates were available to fully evaluate this factor. Large community well systems, defined as systems with more than two wells, were found to have a proportion of detections of any pesticide of 15.0 percent, while small systems, defined as systems with one or two wells, had a proportion of detections of 5.0 percent, with a p-value for the difference in proportions of 0.0002. For nitrate, the difference was not significant. Second, the recharge areas of CWS wells and rural domestic wells, a factor that the NPS could not examine because data on recharge areas were not collected, could differ significantly. Third, the differences in the results might be related to differences between agricultural and non-agricultural uses of pesticides, and particularly to non-agricultural uses of DCPA. However, conclusive information on the balance between agricultural and non-agricultural uses of DCPA was not available. As Exhibit 4-1 indicates, DCPA and its acid metabolites were detected in only one of the surveys described (the Iowa State-Wide Rural Well-Water Survey) in addition to the NPS.

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[1] Holden, L.R. and J.A. Graham, February 1990. The National Alachlor Well Water Survey: Project Summary. Monsanto Agricultural Company, St. Louis, Missouri, Volume 1 of 7. (Hereafter NAWWS Project Summary)

[2] Iowa Department of Natural Resources, [1989], Iowa State-Wide Rural Well-Water Survey: Summary of State-wide Results and Study Design; Perspectives on the SWRL Results; Summary of Results: Pesticide Detections; Summary of Results: Atrazine Detections; Summary of Results: Nitrate and Bacteria. LeMasters, G. and D.J. Doyle, April 1989, Grade A Dairy Farm Well Water Quality Survey, Wisconsin Department of Agriculture, Trade, and Consumer Protection and Wisconsin Agricultural Statistics Service. Groundwater Section, Rhode Island Department of Environmental Management, May 1990, Rhode Island Private Well Survey Final Report, Providence, Rhode Island. Klaseus, T.G., G.C. Buzicky, and E.C. Schneider, February 1988, Pesticides and Groundwater: Surveys of Selected Minnesota Wells, Minnesota Department of Health and Minnesota Department of Agriculture.

Exhibit 4-1: Comparison of Selected

Variable	National Pesticide Survey		Monsanto National Alachlor Well Water Survey
	Community Water System Wells	Rural Domestic Wells	
Type of wells sampled	Public	Private, rural	Private, rural
Study area	Throughout nation	Throughout nation	All counties where alachlor reported sold
Sampling period	April 1988 - February 1990	April 1988 - February 1990	June 1988 - May 1989
Number of wells sampled	540	752	1,430
Wells containing nitrate (%)	52.1 > 0.15 mg/L	57.0 > 0.15 mg/L	> 50
Nitrate minimum reporting limit	0.15 mg/L (ppm)	0.15 mg/L (ppm)	Reported all values
Wells containing nitrate above 10 mg/L (%)	1.2	2.4	5
Wells containing at least one pesticide (%)	10.4	4.2	Not reported
Wells containing pesticides above drinking water standards (%)	0.8	0.6	Not reported
Wells containing atrazine (%)	1.7	0.7	12
Atrazine minimum reporting limit	0.12 µg/L (ppb)	0.12 µg/L (ppb)	Reported all values
Wells containing DCPA or DCPA acid metabolites (%)	6.4 (DCPA acid metabolites)	2.5 (DCPA acid metabolites)	Not analyzed
Number of different pesticides detected/number pesticide analytes	7/126	10/126	5/5
Pesticides detected	atrazine DCPA acid metabolites dibromochloropropane dinoseb hexachlorobenzene prometon simazine	alachlor atrazine bentazon DCPA acid metabolites dibromochloropropane ethylene dibromide ethylene thiourea gamma-HCH prometon simazine	alachlor atrazine cyanazine metolachlor simazine
Analytical method:			
single column chromatography	Yes	Yes	No
second column chromatography confirmation	Yes	Yes	No
mass spectrometry	Yes	Yes	Yes

Drinking Water Well Surveys

Rhode Island Private Well Survey	Minnesota Departments of Health (MDH) and Agriculture (MDA) Surveys		Iowa State-Wide Rural Well-Water Survey	Wisconsin Grade A Dairy Farm Well Water Quality Survey
	MDA Study	MDH Study		
Private, urban and rural	Monitoring (observation) wells[1], private drinking water wells, and irrigation wells	Public	Private, rural	Dairy farm wells
Statewide	Agricultural regions with vulnerable ground water[2]	Agricultural regions with vulnerable ground water[2]	Statewide	Grade A dairy farms statewide
1986	July 1985 - June 1987	July 1985 - June 1987	April 1988 - June 1989	August 1988 - February 1989
463	100	400	686	534
31	61% of the wells > 1 mg/L (ppm)	47.3	60% of wells < 3 mg/L (ppm)	65
0.1 mg/L (ppm)	1 mg/L (ppm)	0.4 µg/L (ppb)	0.1 mg/L (ppm)	0.5 mg/L (ppm)
1	23	7.1	18.3	10
11	51	28.5	13.6	13
0	Not reported	Not reported	1.2	Insufficient data to estimate
Not reported	47	26.8	8	12
0.05 µg/L (ppb)	0.01 µg/L (ppb)	0.01 µg/L (ppb)	0.1 µg/L (ppb)	0.15 µg/L (ppb)
Not detected (DCPA)	Not analyzed	Not analyzed	0.4 (DCPA)	Not detected (DCPA)
7/26	8/30	12/30	15/27 plus selected metabolites	4/44
atrazine aldicarb butylate carbaryl carbofuran dicamba dinoseb	alachlor aldicarb atrazine cyanazine dicamba metribuzin pentachlorophenol simazine	2,4-D 2,4,5-T alachlor atrazine cyanazine dicamba EPTC MCPA metolachlor metribuzin picloram propachlor	2,4-D 3-hydroxy-carbofuran 3-keto-carbofuran alachlor atrazine cyanazine dacthal (DCPA) deethyl-atrazine desopropyl-atrazine hydroxy-alachlor metolachlor metribuzin pendamethalin propachlor trifluralin	alachlor atrazine metolachlor metribuzin
Yes	Yes	Yes	Yes	No
Yes	Yes	Yes	No	No
No	No	No	No	Yes

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[1] Wells were originally installed and monitored by the Minnesota Department of Natural Resources or the United States Geological Survey.

[2] Agricultural regions of the state and, within those regions, areas where local or regional soils and hydrogeologic conditions make the ground water susceptible to pesticide contamination.

4.1 Major Results

This section reports the results discussed in Chapter 3, organized to address the five major factors expected to affect contamination. The results are evaluated with respect to the quality of the data that support them; their consistency with the results obtained by other studies, particularly other surveys of pesticides or nitrate in ground water; and their consistency with major existing theories concerning the presence of pesticides in well water.

4.1.1 Results for Sensitivity Factor

Sensitivity was defined, for this review of the analytic results, as the intrinsic susceptibility of an aquifer to contamination. Sensitivity addresses the hydrogeologic characteristics of the aquifer and the overlying soil and geologic materials, and is unrelated to agricultural practices or pesticide characteristics. Aquifer vulnerability now is considered by EPA to be a more comprehensive term than sensitivity. It encompasses the susceptibility of an aquifer to contamination from the combined effects of its sensitivity, agricultural practices, and pesticide characteristics.[3] However, during the design (stratification) and implementation of the NPS, the term vulnerabiity and its derivatives had approximately the same meaning as sensitivity now has been given.

These measures of sensitivity or vulnerability apply to the ground water lying directly under the area of study. Sensitivity at any particular well drawing water from the aquifer is not measured. Other measures, including the flow of ground water in the area, are important in determining a particular well's sensitivity. Wells in a highly sensitive area, however, would generally be more sensitive to contamination than wells drawing water from a less sensitive aquifer.

Analytic results for the sensitivity factor were available from several different sources. They came, first, from the analysis of DRASTIC scoring. DRASTIC results assessed sensitivity factors at the county and the sub-county level. In addition, sensitivity factors were addressed in NPS questionnaire data, where they provided data at a well-specific level.

All of the ground-water sensitivity variables found to be associated with pesticide or nitrate detections at or below the 0.05 level of significance are listed in Exhibit 4-2.

Overall, the results reported in Exhibit 4-2 do not present a strong pattern of relationships between aquifer sensitivity variables and detections in individual drinking water wells. DRASTIC scores and subscores for underlying ground waters in the NPS did not perform well as indicators of pesticide or nitrate detections in individual drinking water wells. Although there is evidence that some DRASTIC factors for underlying aquifers are related to pesticide or nitrate detections in either CWS or rural domestic wells, the evidence is not recurring or consistent across both categories of wells. In general, the DRASTIC analyses reported contain more occurrences of evidence opposing, rather than concurring with, the hypothesis that aquifer sensitivity, as measured by DRASTIC, would correlate with detections in individual drinking water wells. The lack of a consistent pattern linking contamination of wells with aquifer sensitivity as measured by DRASTIC is also confirmed by the analysis of stratification variables presented in Section 3.1.

Comparison of analyses of county-level DRASTIC scores for underlying ground water with detections in CWS wells and rural domestic wells do not yield similar results for pesticide and nitrate detections. For example, depth to water appears to be associated with pesticide detections in CWS wells, but there is no evidence of a similar relationship in rural domestic wells. Aquifer media is significantly related to nitrate detections for both CWS wells and rural domestic wells at the county level, but in the opposite manner from

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[3] A Review of Methods for Assessing the Sensitivity of Aquifers to Pesticide Contamination, Report prepared for USEPA by Geraghty & Miller, Inc. and ICF Incorporated, March 1991.

Exhibit 4-2

Summary of Ground-Water Sensitivity Variables Associated with Detections in Drinking Water Wells

Variable	Nitrate				Pesticides			
	Community Water System Wells		Rural Domestic Water Wells		Community Water System Wells		Rural Domestic Water Wells	
Level of Measurement Variable Name	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value
COUNTY*								
Average DRASTIC Score	-	< 0.0005						
Depth to water** subscore					+	0.011		
Net recharge subscore	-	0.003						
Aquifer media subscore	-	0.004	-	0.034				
Topography subscore			+	0.044				
Hydraulic conductivity subscore	+	0.001						
SUB-COUNTY*								
Aquifer media subscore	N/A	N/A	-	0.036				
Impact of vadose zone subscore					N/A	N/A	+	0.020
Hydraulic conductivity subscore	N/A	N/A	-	0.006				
WELL								
Well draws water from unconfined aquifer	+	0.002						

N/A - Variable was not measured or not included in survey questionnaires

* The analysis was carried out for DRASTIC scores or subscores, not actual measurements of the listed factors.

** The DRASTIC system assumes that there is a greater chance for attenuation to occur as the depth to water increases. Higher scores for depth to water therefore reflect shallower depths.

that expected. No relationship was identified for rural domestic well detections and aquifer media. Overall, there are very few occurrences of sufficient evidence to suggest a relationship supporting the DRASTIC hypothesis.

Although DRASTIC at the sub-county level was more locally measured than DRASTIC at the first stage, there is insufficient evidence based on the DRASTIC analyses for rural domestic wells at both stages to suggest that DRASTIC measures of ground-water sensitivity at the sub-county level performed better in predicting pesticide or nitrate detections in individual wells than DRASTIC at the county level. There is some evidence that impact of vadose zone is an indicator of pesticide detections at the sub-county level, but no other DRASTIC factors were shown to be associated with pesticide detections at either the county or sub-county levels in rural domestic wells. As an indicator of nitrate detections, topography is the only DRASTIC variable that appears to perform well at the county level for rural domestic wells and no DRASTIC factors at the sub-county level are indicators of nitrate detections in individual wells. DRASTIC at the sub-county level does appear to be an indicator of well nitrate concentrations, but this finding is not supported by analysis of county-level DRASTIC factors with respect to nitrate concentrations, and it appears contrary to not finding a relationship with nitrate detections.

County-Level DRASTIC

At the county level, as Exhibit 4-2 shows, the overall DRASTIC score either was not associated with detections in individual wells, or in the case of nitrate detections for CWS wells was associated in a manner contrary to the design of DRASTIC. If DRASTIC had functioned as expected, detections were more likely to be associated with higher DRASTIC scores. DRASTIC was designed to address areas larger than 100 acres in size.[4] Although no upper limit for effective application of DRASTIC is defined, application to areas the size of counties may significantly exceed the optimum feasible area, since a county-sized area of approximately 1,000 square miles equals about 640,000 acres. Prior to first stage stratification, the time necessary to map a county of 1,000 square miles was estimated to be between 200 and 300 person hours and the time necessary to classify all counties in the United States using the full DRASTIC system was estimated at between 300 and 450 person-years of effort.[5] For purposes of first-stage stratification, however, the NPS designers concluded some misclassification could be tolerated, if it was not extensive. Therefore, a modified DRASTIC system was applied in the first-stage coding that could be scored using on average only a few person-hours of effort.[6] The distribution of scores was found to coincide "reasonably well" with known hydrogeologic conditions in certain ground-water regions. Because 60 percent of the scores were distributed in the moderate vulnerability category, the likelihood of misclassification of a county between the high and low categories was reduced. Independent rescoring of two subsamples of counties indicated that there was appreciable measurement error in county-level scores, but the error was "not large enough to obscure actual differences in vulnerability among counties."[7] Average variations in scores were found to be probably less than 13 percent of a given mean score.[8] The DRASTIC scores therefore were found to meet the stratification needs of the NPS.

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[4] DRASTIC: A Standardized System, pp. 1, 11, 43-44.

[5] Alexander, W.J. and S.K.Liddle, 1986, Ground Water Vulnerability Assessment in Support of the First Stage of the National Pesticide Survey, Proceedings of the Agricultural Impacts on Ground Water Conference, Omaha, Nebraska, pp. 77-87, National Water Well Association, Dublin, Ohio.

[6] Alexander, W., S. Liddle, R. Mason, and W. Yeager, Ground-Water Vulnerability Assessment in Support of the First-Stage of the National Pesticide Survey, February 14, 1986, pp. 1-2 (hereafter Ground-Water Vulnerability Assessment).

[7] Ground-Water Vulnerability Assessment, p. 3.

[8] Ground-Water Vulnerability Assessment, p. 4.

Second-stage DRASTIC scoring, to identify vulnerable sub-county areas in the 90 counties chosen for sampling of rural domestic wells, was carried out at a level of effort much closer to the estimate for county scoring. Approximately 150 to 200 person hours were expended per county for the definition of the "cropped and vulnerable" areas.

The DRASTIC system is designed to culminate in a single numeric value -- the DRASTIC index or overall score -- for any hydrogeologic setting. Although individual subscores may dominate or override the general index they generally are not interpreted separately in the DRASTIC system.[9] The Phase II analysis, however, did test for associations between detections and individual DRASTIC subscores as well as the overall DRASTIC index. DRASTIC subscores for county-level scoring (depth to water, net recharge, aquifer media, topography, and hydraulic conductivity) were found to be associated with detections, but primarily in the wrong direction. These results do not indicate that the subscores are good indicators of contamination. Relatively few associations were identified, considering the number of tests that were performed, and the associations that were identified were not consistent over both CWS wells and rural domestic wells or over both pesticides and nitrate. A larger number of associations were identified between DRASTIC subscores and nitrate detections, but this is due to the larger number of nitrate detections.

For four of the seven statistically significant results reported in Exhibit 4-2 at the county level, the possible effect was contrary to that expected from the underlying hypothesis of the DRASTIC system.[10] The results of tests of association between detections and net recharge suggest that a greater number of detections can be expected with smaller quantities of water per land area penetrating the ground surface and reaching the water table. DRASTIC scoring, in contrast, is based on the theory that higher rates of recharge create a greater potential for ground-water contamination. (This result, however, is consistent with the significant associations found between higher levels of precipitation and fewer nitrate detections discussed in Section 4.1.3 of this chapter.) The result for aquifer media, which was negatively associated with detections of nitrate in both CWS wells and rural domestic wells, suggests that lower values for this DRASTIC subscore are associated with detections of nitrate. DRASTIC, however, gives higher scores to aquifer media with larger grain sizes and more numerous fractures or openings, which are expected to lead to greater permeability and less attenuation through sorption, reactivity, and dispersion. Thus, the negative association is contrary to the expected relationship.

The results of the analysis suggest that higher DRASTIC scores for topography are associated with a greater likelihood of pesticide detections. Because DRASTIC gives higher scores to terrain of more gradual (0 to 6 percent) slope, on the consideration that steeper topography will cause faster runoff and reduced infiltration, this result supports the theory underlying DRASTIC. NPS questionnaire data for topography show that approximately 32.5 percent of CWS wells were reported as located on a "flat valley," with about 20 percent located on a hillside and about 21.7 percent in an unspecified topographical setting. About 34.6 percent of rural domestic wells were reported on a "flat valley," with 33.5 percent on a hillside and 16.7 percent on a hilltop. Analysis of topography as a questionnaire variable, however, did not reveal a significant association paralleling the result for the analysis of the DRASTIC topography subscore.

Higher scores for hydraulic conductivity were found to be related to a greater likelihood of nitrate detections in CWS wells. Because DRASTIC is designed to give higher scores to aquifer materials with a greater ability to transmit water, and ground-water flow is considered to control the rate of contaminant movement, this result corresponds to the underlying basis upon which DRASTIC was designed. NPS questionnaires did not collect data on hydraulic conductivity; instead, default values were used.

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[9] DRASTIC: A Standardized System, pp. 80-83.

[10] DRASTIC: A Standardized System, pp. 17-67.

Well owners/operators of community water systems were asked if the aquifer from which water was drawn was a confined aquifer.[11] Approximately 43.5 percent of CWS wells were reported to draw from a confined aquifer. Equivalent data were not obtained for rural domestic wells. Analysis of the confined/unconfined aquifer questionnaire data showed that detections are associated with unconfined aquifers, paralleling the result for the analysis of the DRASTIC hydraulic conductivity variable.

One county-level DRASTIC subscore, depth to water, was associated with pesticide detections in CWS wells only. DRASTIC scoring gives lower ratings to situations in which the depth to water is greater, since attenuation is presumed to be more likely as the depth to water increases. The association between higher scores (reflecting shallower depth to ground water) for this DRASTIC component and pesticide detections therefore is consistent with the basis of DRASTIC's design. This result also is consistent with the results for the analysis of the well depth variable from NPS questionnaire data, discussed under well-level variables later in this section. Results for the analysis of this variable also are consistent with the association between pesticide detections in CWS wells and the county-level DRASTIC subscore for depth to water. Strong negative associations were identified between nitrate detections in both categories of wells and pesticide detections in CWS wells and shallow wells. The association between shallow CWS wells and pesticide detections also is consistent with findings of the Iowa State-Wide Rural Well-Water Survey. That survey, conducted in 1988-89, reported more frequent pesticide detections and higher concentrations in wells less than 50 feet deep than in deeper wells.[12]

Sub-County Level DRASTIC

Sub-county DRASTIC scoring was carried out only for rural domestic well stratification. Therefore, no tests of association are possible between detections in CWS wells and sub-county level DRASTIC scores.

No overall sub-county area DRASTIC score for underlying aquifers was found to be associated with detections in individual wells, and only three sub-county subscores -- aquifer media, impact of vadose zone, and hydraulic conductivity -- were related to detections. Of these, scores for aquifer media and hydraulic conductivity were related to nitrate detections in the opposite manner to that expected. The sub-county findings for the association of nitrate detections in rural domestic wells with aquifer media paralleled the findings for the county-level analysis, but in both cases the direction of association (at almost the same significance level) was contrary to that expected. The direction of the relation for hydraulic conductivity was contrary to that obtained when the variable was analyzed for the county-level scoring. The result was for nitrate detections in both cases, with hydraulic conductivity when measured at the county level associated with detections of nitrate in CWS wells in the expected manner (e.g., a greater number of detections are associated with higher DRASTIC scores for hydraulic conductivity) and associated with detections of nitrate in rural domestic wells in the opposite manner when measured at the sub-county level. Thus, the finding for the hydraulic conductivity subscore of DRASTIC is not consistent between county-level scoring and sub-county-level scoring.

Finally, higher DRASTIC subscores for impact of the vadose zone were found to reflect a greater likelihood of pesticide detections in rural domestic wells. The vadose zone media are presumed in DRASTIC scoring to determine the attenuation characteristics of the material above the water table. Because higher scores are given to materials with less attenuation potential, an association between higher scores and a greater likelihood of ground-water contamination corresponds to the theory underlying the DRASTIC model.

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[11] The question was asked only for CWS wells (CWS Main Questionnaire, Question A25).

[12] Iowa State-Wide Rural Well-Water Survey: Summary of State-Wide Results and Study Design, p. 4; Perspectives of the SWRL Results, p. 1.

In summary, results concerning sensitivity variables are not consistent. At the time the NPS was being designed, the National Water Well Association cautioned that DRASTIC had not been designed to yield a single numeric vulnerability score for a county and the problem would be magnified in larger counties. The 1985 Scientific Advisory Panel subpanel also noted that some DRASTIC parameters overlapped or were not strictly related to actual vulnerability, and that DRASTIC pertained to shallow water vulnerability.[13] The Phase II results suggest that DRASTIC did not perform well as applied in the NPS. The poor performance of DRASTIC measures of underlying aquifers and detections in individual wells may be due to several factors, including measurement error, caused by measuring the DRASTIC variables on too gross a scale relative to well sites. Site-specific factors for the individual wells sampled, such as recharge and flow of ground water, may prevent the well from being representative of the county or sub-county vulnerability. Although wells draw water from an aquifer that may be affected by a large recharge area, county and sub-county averages are probably too large to produce accurate data concerning ground-water vulnerability at a particular well site.

The NAWWS also used a county-level DRASTIC score as a measure of relative ground-water vulnerability. NAWWS constructed three well-specific hydrogeologic measures for each sample well. The first, well-specific vulnerability, was based on a classification of the aquifer tapped by the well as surficial (most vulnerable), confined (least vulnerable) and intermediate (moderate vulnerability). The second estimated relative water level (low, moderate, or high) at the time of sampling and identified water level with recharge. The third was a DRASTIC score for the aquifer tapped by the sample well.[14] NAWWS concluded that alachlor detections were associated with "highly vulnerable" wells and that the best general measure of vulnerability was the well-specific vulnerability measure based on the type of aquifer tapped by the well. In contrast, NAWWS, like the NPS, found that DRASTIC did not work successfully to identify vulnerable drinking water wells.[15]

Well-Specific Variables

The NPS obtained strong results indicating an association between both nitrate and pesticide detections and shallower wells. These results were consistent for nitrate in both CWS wells and rural domestic wells and for pesticides in CWS wells.

Well-specific variables pertaining to sensitivity were obtained from NPS questionnaires rather than DRASTIC scoring. Data were collected about the distance from the ground surface to the water surface in the well. Respondents appeared to be aware of the depth of their wells; only about 5.5 percent of the respondents to the CWS main questionnaire answered that they did not know the depth of the well and about 5.4 percent of respondents for rural domestic wells did not know the depth of the well. The extent of respondent error concerning estimates of well depth, however, cannot be determined. Interviewer debriefing found that only a small number of rural domestic well respondents (about 5%) had records from which they could obtain a precise well depth, but interviewers concluded that about 75% of the respondents could estimate a depth range to the nearest 50 feet.[16]

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[13] NPS Phase I Report, Appendix A, pp. A-9 to A-10. See also Banton, O. and J.P. Villenueve, 1989, Evaluation of Groundwater Vulnerability to Pesticides: A Comparison Between the Pesticide Drastic Index and the PRZM Leaching Quantities, Journal of Contaminant Hydrology, 4, pp. 285-296.

[14] NAWWS Project Summary, pp. 13-14.

[15] NAWWS Project Summary, p. 17.

The results for well depth are consistent with the studies of pesticides in wells conducted by the Minnesota Departments of Health (MDH) and Agriculture (MDA) and the results of the Iowa State-Wide Rural Well-Water Survey. In the Minnesota studies, pesticides were detected more frequently in observation and private drinking water wells than in public drinking water wells. MDH and MDA suggest that this difference is most likely attributable to the shallower depths of many of the observation and private drinking water wells.[17] MDH and MDA also attribute the result to the proximity of observation and private wells to fields receiving pesticide applications, and do not specify which association is stronger. The Iowa study detected contaminants, including pesticides and nitrate, more frequently and at higher concentrations in wells less than 50 feet deep than in wells deeper than 50 feet.[18]

4.1.2 Results for Pesticide and Fertilizer Use Factor

Use was defined for the NPS Phase II analysis as the scope and timing of applications of pesticides and nitrogen fertilizers, and the scope and timing of activities, such as agricultural practices, that could contribute to the presence of pesticides or nitrate in places where they could be transported into wells.

Analytic results addressing the use factor were available from a broad range of data sources. First, a study was done to determine if the NPS data indicated any temporal effect due to disproportionate sampling in seasons of particularly high or low pesticide and nitrate use. Data relating to use variables were then analyzed from several sources:

- Questionnaire data pertaining to areas near the well, within 1/2 mile of the well, and in the county, both from well owners and from county agricultural extension agents;
- County-level pesticide data available to EPA from sources outside the NPS; and

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[16] Summary of NPS Domestic Well Survey Field Interviewer Debriefing on March 9, 1990, Memorandum from Leslie Athey to David Marker, August 16, 1990, p. 5 (Hereafter Debriefing Summary).

Data on well depth were distributed as follows:

	National Estimates for CWS Wells			National Estimates for Rural Domestic Wells	
Well depth:	Number	Percent	Well depth:	Number	Percent
< 20 feet	260	0.3	< 20 feet	385,000	3.7
20 to 50 feet	4,410	4.7	20 to 50 feet	1,160,000	11.0
51 to 100 feet	14,900	15.8	51 to 100 feet	2,170,000	20.7
101 to 200 feet	16,600	17.6	101 to 200 feet	2,860,000	27.2
201 to 500 feet	33,400	35.3	201 to 500 feet	1,930,000	18.4
> 500 feet	19,800	20.9	> 500 feet	424,000	4.0
Don't Know	5,150	5.5	Don't Know	1,580,000	15.1

[17] Klaseus, T., G. Buzicky, E. Schneider, Pesticides and Groundwater: Surveys of Selected Minnesota Wells, Prepared for the Legislative Commission on Minnesota Resources, February 1988, p. ix. Medians and ranges for well depth are summarized at pp. 78 to 88.

[18] Iowa State-Wide Rural Well-Water Survey, Perspectives of the SWRL Results, p. 1. Statewide, 27.9 percent of private drinking water wells are less than 50 feet deep, but in the western and southern portions of the state over 50 percent of the wells are less than 50 feet deep.

- County-level data on nitrogen sales and farming practices from sources outside the NPS.

A summary of all the use variables found to be associated with pesticide or nitrate detections is presented in Exhibit 4-3.

The evaluation of use variables led to mixed results. The investigation of pesticide use patterns reported by NPS participants did not identify a relationship between pesticide use, as reported on NPS questionnaires, and pesticide detections. In a number of cases, pesticides were detected in wells when neither the well owner nor the county extension agent had reported use of that pesticide near the well.

In contrast, analysis of pesticide and nitrate use data reported from other sources found several strong associations between use and pesticide or nitrate detections. These associations are based on county-level pesticide and fertilizer use measures. They therefore are subject to an averaging effect, which is discussed in Chapter 3.

NPS Pesticide and Fertilizer Use Data

Pesticides

Questionnaire responses concerning farming activities and pesticide use on the property or within one-half mile of the well may help to explain the failure to identify a relationship between agricultural pesticide use and pesticide detections based on questionnaire data. A large proportion of the respondents did not indicate that any pesticides had been used within the specified time periods and proximities of the sampled wells. Only approximately 7.4 percent of respondents reported farming on the CWS property during the past five years, and of these only 34 percent reported pesticide use on the property. About 40.3 percent reported crops farmed within one-half mile and only about 19.8 percent reported non-agricultural pesticide use within one-half mile in the previous three years. For rural domestic wells, only about 11.7 percent of respondents reported that the property upon which the well was located was farmed. That is, the wells were located in rural areas, as defined in the NPS, but were not situated on farmed land. Of the farmed properties, about 83.6 reported use of pesticides in the past five years. Approximately 66.2 percent of rural domestic well respondents did report that crops were farmed within one-half mile of the well in the past three years.

Whenever possible, questionnaire responses were cross-checked. In addition, interviewers for the rural domestic well questionnaires were debriefed following data collection. The debriefings indicated that considerable probing was necessary to obtain complete lists of pesticides used, stored, and disposed on the property. Interviewers reported that the information obtained did reflect the respondents' best knowledge of pesticide use around the well. However, respondents frequently were not able to estimate distances accurately between storage and disposal sites and the well. Many respondents used considerable amounts of pesticides for situations not explicitly covered in the questionnaire, or for livestock that did not earn at least $1,000 per year, the reporting cutoff. Respondents' reports of disposal of pesticides and pesticide containers on the property may underestimate the actual incidence of disposal. Interviewers also reported that the information provided by county agricultural extension agents did not represent first-hand knowledge of pesticide use for a particular site. County agricultural extension agents were knowledgeable about what crops were grown in different parts of their county, and could provide lists of common pesticides for those crops but their responses were usually not specific to the sampled well. Finally, respondents were sometimes uncertain whether their activities constituted use, storage, or disposal of "agricultural" pesticides.[19]

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[19] Debriefing Summary, pp. 3-5.

Exhibit 4-3

Summary of Pesticide and Fertilizer Use Variables Associated with Detections in Drinking Water Wells

Variable	Nitrate				Pesticides			
	Community Water System Wells		Rural Domestic Water Wells		Community Water System Wells		Rural Domestic Water Wells	
Level of Measurement Variable Name	Direction of Effect	p-value	Direction of Effect	p-value	Direction of Effect	p-value	Direction of Effect	p-value
COUNTY								
Market value of livestock	+	0.02						
Market value of crops							+	0.002
Fertilized pastureland and rangeland (acres)	-	0.001			-	0.007		
SUB-COUNTY								
Land used for pasture within half mile of the well since January 1, 1986			+	0.013				
Pesticide retail outlet within half mile of the well			+	0.013				
Property farmed	+	0.022						
Beefcows (numbers)	-	0.003			-	0.021	-	0.043

EPA's experience in the evaluation of farming practices and pesticide application suggests five reasons that reports of pesticide use may be inaccurate:

(1) Chemical applications may be performed in the absence of the landowner, and are ordinarily applied in the absence of county agricultural extension agents, and may differ from the planned or recommended application;

(2) Application equipment may be malfunctioning or poorly calibrated;

(3) Actual application rates may vary significantly even with properly calibrated equipment;

(4) Recordkeeping can be poor, or good records may not be consulted; and

(5) Some conscious misreporting may have occurred.

The NPS results for pesticide use contrast strongly with the results obtained by the NAWWS survey. That survey found that about 64 percent of all wells are within 300 feet of a cropped area, field, or pasture. NAWWS estimated (for the alachlor use area) that 85 percent of the wells had row crops grown within a half mile and 20 percent of the wells are in intense row cropping areas. NAWWS also estimated that 59 percent of the wells in the target population had alachlor use within a half mile during the past 5 years and 50 percent had alachlor use within the past year. Atrazine was estimated to have been used within a half mile of 55 percent of the wells during the past 5 years, and 22 percent of the wells were located in intense fertilizer application areas.[20]

Nitrate

Information obtained from questionnaires on sources of nitrate also was subject to variability stemming from several causes. Respondents were knowledgeable about the use of nitrogen fertilizer, but frequently reported multiple applications and different rates of application on different parts of the property, making recording of the data more difficult. When fertilizer services were used, respondents sometimes could not provide exact information about application rates. Respondents also sometimes answered "yes" to the presence of both a septic system and a cesspool when they had only one system.[21]

A significant association was identified in the analysis of NPS questionnaire data between the presence of a pesticide retail outlet within one-half mile of a rural domestic well and nitrate detections.
Interviewers noted in connection with the questions that elicited information about pesticide retail outlets that respondents who were concerned about the location of certain facilities near wells sought to make certain that the interviewers recorded them. The result for pesticide retail outlets is based on a relatively small number of positive responses. Approximately 7.3 percent of the well owners reported the presence of a pesticide retail outlet near the well.[22] Although pesticide retail outlets also frequently may be nitrogen fertilizer outlets,

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[20] NAWWS Project Summary, pp. 14-15.

[21] Debriefing Summary, p. 4.

[22] Results for this variable were not reported in the NPS Phase I Report, Appendix D. For those respondents who answered the question with a response other than "Don't Know," the results (for Local Area Domestic Well Questionnaire, Question 11n) are as follows:

Is there a pesticide retail outlet within one-half mile of the well:		
	Yes	7.3%
	No	92.7%

the result must be considered in light of the relatively small number wells sampled that are near pesticide retail outlets.

The second significant use variable identified from questionnaire data is for land used for pasture within one-half mile of rural domestic wells. It is associated with a greater likelihood of nitrate detections in rural domestic wells. Approximately 65.4 percent of respondents reported pasture within one-half mile, with a "don't know" response rate of only about 1.9 percent.

Surrogate Measures of Pesticide and Fertilizer Use

Several variables derived from data on agricultural activities and fertilizer sales were strongly associated with nitrate and pesticide detections. In particular, the market value of crops, which may be considered a surrogate for pesticide use, is associated with pesticide detections in rural domestic wells. The market value of livestock, a possible surrogate for the generation of nitrate by animals, is strongly associated with nitrate detections in CWS wells. These variables are based on data collected by Resources for the Future and by the Division of Resources Management at West Virginia University in conjunction with the National Fertilizer and Environmental Research Center (NFERC).

These results represent county-wide averages and are not direct measures of application rates of fertilizers or pesticides at the well level. The estimates of fertilizer expenditures by farmers used to develop the county estimates are generated by allocating the NFERC state total among counties in proportion to reported expenditures on all fertilizers, as reported by the 1987 Census of Agriculture. Expenditures on fertilizer do not necessarily correspond exactly to tonnage acquired, but the correlation between these variables should be high. The estimated nitrogen sales totals are weighted average state totals, where the weights correspond to expenditures on fertilizers. Because the estimated nitrogen sales data are constructed consistently for all counties, these data were used instead of the state-supplied NFERC data. In 1989, 30 states submitted county-level data to NFERC. Correlation analysis for states that do submit county information indicates that the estimated values are highly correlated with the state data.

NFERC's estimates are accompanied by several caveats. The data reflect total sales of fertilizer without regard to whether the fertilizer was purchased for agricultural or other uses; sales do not indicate where or when the fertilizer was used; and the estimates do not include manure.[23]

The analysis found evidence of a relationship between nitrogen fertilizer sales data and nitrate concentrations. Higher amounts of nitrogen sold per county acre was found to be associated with higher concentrations of nitrate in both CWS and rural domestic wells. In addition, several Census of Agriculture variables, particularly value of crops and livestock and acres of cropland fertilized, were found to be associated with nitrate concentrations. The analysis did not identify relationships between the NFERC variables and nitrate detections. Only very weak evidence for an association between pesticide detections and nitrogen fertilizer sales was identified.

These results fall between those reported in the Minnesota and NAWWS studies. The Minnesota survey sought to determine if there was a relationship between nitrate and pesticide occurrence and concentration in ground water and whether nitrate testing might be a surrogate for pesticide testing. A clear relationship between pesticide and nitrate occurrence was not observed. When pesticides were detected, nitrate detections were also likely; but wells with detectable nitrate did not contain detectable concentrations of pesticides in 41.6 percent of the cases. Based on the results, nitrates were not found to be a reliable indicator of pesticide occurrence or a quantitative predictor of pesticide concentration.[24]

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[23] Documentation for NFERC/EPA Fertilizer Sales Data.

In contrast, NAWWS found highly significant associations of nitrate levels exceeding 10 mg/L with alachlor, atrazine, and simazine detections. In wells in which nitrate was detected at or above 10 mg/L, atrazine was detected at a frequency of 43 percent, simazine at a frequency of 9 percent, and alachlor at a frequency of 2 percent.[25]

4.1.3 Results for Transport Factor

Transport is defined as factors that contribute, either directly or indirectly, to the movements of pesticide and nitrate, including precipitation, as well as factors that could inhibit the movement into well water, such as well sheds, pads, or other protective measures for wells.

Results for the transport factor came from several sources. NPS questionnaires gathered data on well construction and protection, water bodies and practices such as irrigation located near wells, and water bodies in sub-county areas surrounding the well. Precipitation and drought data were collected from sources outside the NPS.

A summary of the transport variables found to be related to pesticide and nitrate detections is presented in Exhibit 4-4.

Transport variables, particularly those involving precipitation and the presence of water bodies near sampled wells, show an interesting inverse relationship to detections, particularly strong with respect to nitrate detections. Detections of nitrate in CWS wells are strongly associated with county-level precipitation variables; the probability of detecting nitrate above the NPS minimum reporting limit of 0.15 mg/L in CWS wells is less in counties that record high precipitation. This finding is supported for both short and long term precipitation. Conversely, a lack of precipitation is associated with a higher probability of nitrate detections. The results for nitrate concentrations in CWS wells provide further evidence of the same relationship.

The analysis performed using the Palmer Drought Index also shows that for CWS wells nitrate detections and concentrations are greater in drought areas than in moist areas. Similar results, however, were not obtained for the analysis of rural domestic wells, possibly because rural domestic well sampling occurred in only 90 counties.

Detection of pesticides in CWS wells and rural domestic wells generally is not found to be related to the precipitation and drought variables considered. The percent of detected pesticides in well water under drought conditions is not dissimilar to that for near normal and moist conditions, implying that the presence of drought is not associated with pesticide detections. Both short and long term average precipitation factors do not appear to be related to pesticide detections in CWS or rural domestic wells. The effective sample size for this analysis, however, limits the extension of this result beyond survey data. There is some evidence that occurrence of intense precipitation at some point in the last five years is negatively associated with pesticide detections, but this result is not corroborated by the other highly correlated precipitation variables.

The precipitation variables, including average precipitation occurring close to the time of sampling and precipitation occurring one, two, and five years prior to sampling, all indicated that higher levels of precipitation were associated with fewer nitrate detections. The result, however, was largely confined to nitrate in CWS wells, although higher precipitation in the two years before sampling also was an indicator of fewer

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[24] Klaseus, T., and J. Hines, Pesticides and Groundwater: A Survey of Selected Private Wells in Minnesota, August 1989, pp. xi, 20-21.

[25] NAWWS Project Summary, p. 18.

Exhibit 4-4

Summary of Transport Variables Associated with Detections in Drinking Water Wells

Variable	Nitrate				Pesticides			
	Community Water System Wells		Rural Domestic Water Wells		Community Water System Wells		Rural Domestic Water Wells	
Level of Measurement Variable Name	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value
COUNTY								
Precipitation in prior month	–	0.004						
Precipitation during last year	–	< 0.0005						
Precipitation during last two years	–	< 0.0005			–	0.032		
Precipitation during last five years	–	< 0.0005	–	0.005				
Drought (PDI)	–	0.046						
SUB-COUNTY								
Surface water within half mile	–	0.010	–	0.015				
Drainage ditch within half mile	–	0.019	–	0.000				
Drainage ditch within 300 feet	–	0.030						
Flood irrigation within half mile	+	0.019						
Groundwater used for irrigation within one-half mile			–	0.033				
WELL								
Other operating wells within 500 feet			+	0.043	+	0.006		
Surface water within 300 feet of the well			–	0.037	–	0.014		

pesticide detections in CWS wells. One precipitation variable, five-year precipitation, was associated with fewer nitrate detections in rural domestic wells. Thus, the precipitation variables, all of which were measured at the county level, consistently showed the same general tendency.

The evidence from other studies concerning pesticide detections and precipitation is mixed. Ground-water monitoring in central South Dakota on a monthly basis from 1984 to 1989 shows a higher rate of detections in 1988 and 1989, years in which annual precipitation was lower. No correlation was observed between total annual precipitation and the number of pesticide detections per year.[26] In contrast, the Iowa State-Wide Rural Well-Water Survey experienced a lower frequency of pesticide detections and lower concentrations of nitrate detections in rural private wells during 1988 and 1989, the two driest consecutive years in the state's recorded history.[27] Monitoring in Minnesota between 1986 and 1989 showed detections at high concentrations in 1986, a wet year, and a decrease in the number and frequency of detections in 1988, an extremely dry year in the state, suggesting that higher concentrations and frequency of occurrence are associated with increased precipitation.[28]

These results may suggest that factors that may lead to the frequent and extensive infiltration or runoff of water near the well are associated with a reduced likelihood of detections, particularly for nitrate detections in CWS wells. The evidence is insufficient to suggest the same conclusion for pesticides, and the results of other surveys are not fully corroborative. A possible reconciliation of the NPS results for precipitation and the results reported from other surveys is that the association of recharge and ground-water contamination holds except for situations of extremely low or extremely high recharge. In the former case, under very dry conditions, insufficient recharge may occur to mobilize contaminants. In the latter case, very high amounts of recharge may lead to dilution of contaminants and a reduction in the potential for ground-water contamination.[29] The Minnesota Department of Agriculture is currently studying climatic influences on pesticide concentration and detection, in part to investigate whether pesticides are immobilized during drought conditions by material in the enlarged vadose zone and by the absence of infiltrating water to transport pesticides.[30]

It is important to bear in mind, however, that several processes could be occurring. The NPS did not collect information seeking to define the recharge area of sampled wells, and consequently cannot assess the impact of the recharge area on results. Local rainfall may not occur in the aquifer recharge area or local precipitation may have a smaller impact on the aquifer than cropping and pesticide use and other land use in the recharge area. Secondly, the impact of precipitation runoff cannot be evaluated, nor can the impact of antecedent soil moisture.

NPS results suggest that fewer pesticide and nitrate detections can be expected if surface water (rivers, canals, bays, springs, and ponds) or drainage ditches are located within one-half mile of either CWS wells or rural domestic wells. Similarly, fewer nitrate detections can be expected for CWS wells with drainage ditches within 300 feet. Approximately 83 percent of CWS wells were reported to have surface water within one-half mile, while approximately 93.8 percent of rural domestic wells were within one-half mile of such surface water bodies. Surface water within 300 feet of CWS wells and rural domestic wells also was associated with a reduced likelihood of pesticide and nitrate detections, respectively.

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[26] Kimball, C., and J. Goodman, Non-Point Source Pesticide Contamination of Shallow Ground Water, 1989 International Winter Meeting, American Society of Agricultural Engineers, pp. 7-9.

[27] Iowa State-Wide Rural Well-Water Survey: Summary of State-Wide Results and Study Design, p. 2.

[28] Minnesota Department of Natural Resources, Drought of 1988, January 1989; Klaseus, T., and J. Hines, Pesticides and Groundwater: A Survey of Selected Private Wells in Minnesota, Minnesota Department of Health, Report Prepared for the United States Environmental Protection Agency, August 1989.

[29] DRASTIC: A Standardized System, pp. 47 and 64. The DRASTIC ranges and associated ratings do not reflect any dilution factor.

[30] Communication between Minnesota Department of Agriculture and Director, National Pesticide Survey, July 1991.

A number of results at the well level also reflected the influence of transport-related factors. Flood irrigation within one-half mile of CWS wells was associated with a higher number of nitrate detections, although fewer than 25 percent of CWS wells reported such irrigation nearby. Leaching of nitrate to ground water from irrigated fields has been documented.[31] Presence of another operating well within 500 feet also was associated with an increased likelihood of nitrate detections in CWS wells and of pesticide detections in rural domestic wells.

EPA evaluated the differences in detections between small community well systems, defined as systems with one or two wells, and large community well systems, defined as systems with more than two wells. For the "any pesticide" variable, the difference is significant; the proportion of detections for large community well systems is 15.0 percent and for small is 5.0 percent, with a p-value for the difference in proportions of 0.002. For nitrate, in contrast, the difference is not significant; the proportion of detections is 54.8 percent for large and 48.3 percent for small community well systems at a p-value of 0.196.

4.1.4 Results for Chemical Characteristics Factor

Chemical characteristics are defined as characteristics of pesticides, such as organic partition coefficients (K_{oc}) and half-life, or characteristics of the soil or ground-water, such as temperature, pH, and electrical conductivity that could affect the behavior of pesticides or nitrate. A summary of the results for this factor is presented in Exhibit 4-5.

Well Water Temperature

Low well water temperature is associated with detections of both pesticides and nitrate in CWS wells. For pesticides, this result is consistent with the hypothesis that the rate of pesticide degradation will be slower at low temperatures. The measured well water temperatures ranged from a low of 1 degree centigrade to a high of 37 degrees centigrade, with a mean temperature of approximately 17 degrees centigrade. A recent study of the effect of temperature and other factors on DCPA degradation found that the dissipation rate is largely dependent on soil conditions, including soil temperature. The rate of DCPA degradation increased as soil temperature was increased up to a maximum at 25-30°C, after which it decreased. Soil temperature was shown to contribute more to the rate of DCPA degradation than soil moisture content.[32] The NPS measured ground-water temperature, not soil temperature. Soil temperature varies with depth and time (daily and seasonally). Well water temperature after purging was considered to reflect aquifer temperature.

Association of nitrate detections with lower temperature is more difficult to evaluate. Because the process that controls the oxidation of the ammonium ion is enzymatically limited, cooler soils could be expected to result in less nitrification of ammonium fertilizers to produce nitrate. Without consideration of other factors, the optimum temperature for microbial activity is considered to be between approximately 30 and 35 degrees centigrade.[33] Factors such as the effect of lower temperatures on plant uptake of nitrate and

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[31] Powers, J., and J. Schepers, 1989, Nitrate Contamination of Ground Water in North America, 26 Agriculture, Ecosystems, and Environment, pp. 165-187.

[32] Choi, J., T. Fermanian, D. Wehner, and L. Spomer, 1988, Effect of Temperature, Moisture, and Soil Texture on DCPA Degradation, 80 Agronomy Journal 108-113.

[33] Alexander, M., Nitrification, in Bartholomew, W.V. and Clark, F.E, Soil Nitrogen, American Society of Agronomy, pp. 326-327, 1965.

Exhibit 4-5

Summary of Chemical Variables Associated with Detections in Drinking Water Wells

Variable	Nitrate				Pesticides			
	Community Water System Wells		Rural Domestic Water Wells		Community Water System Wells		Rural Domestic Water Wells	
Level of Measurement Variable Name	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value
WELL								
Well water temperature	-	0.010			-	< 0.0005		
Well water pH	-	0.015	-	< 0.0005	-	0.003		
Well water conductivity	-	0.001						
Well water is hard (high mineral content)			-	0.033				
Half–life ($\log_e$)	N/A	N/A	N/A	N/A	+	0.020		

N/A – Variable was not measured or not included in survey questionnaires the effects of season or temperature on the time or rate of application of nitrogen fertilizers also could affect the relationship.

Well Water pH

The analysis identified an association between between greater numbers of nitrate and pesticide detections and low pH of well water.

For nitrate results this result was contrary to expectation, since nitrification is known to proceed more slowly in acid soil. The range of pH values for samples of well water was pH 4.7 to 9.6, with a mean of 7.4. The optimum range of pH conditions for the Nitrosomonas and Nitrobacter strains of bacteria that are ammonium and nitrite oxidizers is between pH 7 and 9.[34]. Ammonium fertilizers are known to lower the pH of soil through the nitrification process. However, tendencies toward lower pH might be expected to be affected by the buffering capacity of most soils, and thus not to affect the pH of well water. Redox conditions were not measured or evaluated.

Pesticide occurrence in community system wells was found to be associated with low pH; however, domestic wells did not show a reliable association. Low pH in ground water is considered to be a condition that enhances the persistence of pesticides in ground water because hydrolysis, a principal method of degradation, is retarded. In addition, the acid metabolites of DCPA were the most frequently detected chemical.

Well Water Electrical Conductivity

The analysis identified an association between nitrate detections and lower electrical conductivity in CWS well water. This is contrary to the expected result, since nitrate in solution would be likely to increase the conductivity of well water. Measured conductivity values ranged from 0 to 2,500 ppm total dissolved solids (TDS) with a mean of approximately 230 ppm TDS. The survey did not collect sufficient data to explain or analyze this result.

Persistence

The analysis indicated that half-life of pesticides in soil tends to be higher for detected pesticides than for pesticides that were not detected. The finding of a greater likelihood of detecting pesticides with relatively longer half-lives is consistent with the expectation that the longer the time necessary for a pesticide to break down, the greater the possibility that the chemical can migrate below the root zone and leach to ground water. The analysis could be performed for only 64 of the 126 pesticide analytes because accepted half-lives could not be identified for all of the pesticide analytes. Other qualifications are described in Chapter 3.

The EPA also tested a two-variable model, the groundwater ubiquity score or GUS model, which has been proposed as a screening tool to determine if particular pesticides are likely to leach to ground water.[35] The GUS index makes use of pesticide organic partition coefficients (K_{oc} for which no significant results were obtained singly in the Phase II analysis) and measures of half life to calculate an index of leaching potential.

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[34] Alexander, pp. 327-328.

[35] Gustafson, D.I., Groundwater Ubiquity Score: A Single Method for Assessing Pesticide Leachability, 8 Environmental Toxicology and Chemistry 339, 1989.

The GUS index was calculated for each of the 64 chemicals in the NPS for which both half-life and K_{oc} information is available.[36] The predictive capabilities of the GUS index were then measured using a logistic regression approach to determine if the GUS index could predict the probability of detection of an NPS chemical (in either CWS or rural domestic well surveys). The p-value associated with this testing procedure was approximately 0.02, providing evidence that the GUS index is useful for predicting pesticide occurrence in well water samples (according to NPS data).

The mean GUS index for pesticides detected in the NPS was 3.6 (standard error of 0.7), and for non-detected chemicals was 2.2 (standard error of 0.2). These results show comparable performance of the GUS model and the model involving half-life only presented in Exhibit 3-8. Results of the logistic regression procedure are presented in Exhibit 4-6.

Exhibit 4-6

Estimated NPS Logistic Regression Models for the GUS Index

Independent Variables	Intercept	Standard Error	Beta-Coefficient	Standard Error	p-value for Beta
Model 1:					
GUS Index	-2.95	0.79	0.52	0.23	0.023

EPA compared the GUS index analysis with the results of the analysis of half-life and K_{oc} individually. The GUS index does not provide more useful results. The individual analyses suggest that while half-life predicts pesticide occurrence in well water samples, the same is not true of K_{oc}. Although the preferred model includes a half-life term only, there is some evidence that an additive model including both half-life and K_{oc} factors also provides reasonable predictions.[37] Both models are presented in Exhibit 4-7 (the log scale is base 10 for direct comparison with the GUS index analysis):

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[36] The GUS model is:

$$GUS = \log_{10}(\textit{half-life}) \times (4-(\log_{10}(K_{oc})))$$

or:

$$GUS = 4 \log_{10}(\textit{half-life}) - \log_{10}(\textit{half-life}) \times \log (K_{oc}).$$

[37] The data used for the GUS model are the same as the data used for the results presented in Section 3.8 of the NPS Phase II Report. The logistic regression models presented in Exhibits 4-7 and 4-8 may be written, in order, as follows:

$$Logistic(Detection) = \alpha + \beta GUS$$

$$Logistic\ (Detection) = \alpha + \beta Log_{10}(\textit{Half-life})$$

$$Logistic(Detection) = \alpha + \beta_1 Log_{10}(\textit{Half-life}) + \beta_2 Log_{10}(K_{oc})$$

Exhibit 4-7

Estimated NPS Logistic Regression Models for Half-Life and K_{oc}

Independent Variables	Intercept	Standard Error	Beta-Coefficients	Standard Error	p-value for Betas
Model 1:					
Log(half-life)	-3.96	1.19	1.47	0.64	0.021
Model 2:					
Log(half-life)	-2.61	1.34	1.97	0.74	0.008
Log(K_{oc})			-0.99	0.47	0.034

Models including interaction terms did not fit as well as either of these models. Both of these models fit the data better than the model for the GUS index.

4.1.5 Physical Characteristics of Wells

A summary of the variables pertaining to the physical characteristics of wells that were found to be related to pesticide and nitrate detections is presented in Exhibit 4-8. An association was found between detections and two measures of well condition, well age and the presence of a well house over the well. Older wells may be in worse condition than newer wells and therefore more susceptible to contamination; because of the passage of time they may have had a greater likelihood of becoming contaminated even if they are in good condition. About 12.7 percent of the CWS respondents and 14.9 percent of the rural domestic well respondents did not know the age of their well.[38] Interviewers estimated rural domestic well respondents' accuracy at about ± 5 years.[39] NAWWS calculated that at least 30 percent and possibly up to 50 percent of wells in its sampled population were over 20 years old. NAWWS did not report an association between well age and a higher likelihood of detection.[40]

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[38] The data are distributed as follows:

	National Estimates for CWS Wells		National Estimates for Rural Domestic Wells	
Age of Well:	Number	Percent	Number	Percent
< 5 years	5,900	6.2	1,640,000	15.6
5 to 10 years	16,300	17.2	1,710,000	16.3
11 to 20 years	26,700	28.2	3,070,000	29.3
> 20 years	33,600	35.6	2,520,000	24.0
Don't Know	12,000	12.7	1,570,000	14.9

[39] Debriefing Summary, p. 4.

[40] NAWWS Project Summary, p. 15.

Exhibit 4-8

Physical Characteristics of Wells Associated with Detections in Drinking Water Wells

Variable	Nitrate				Pesticides			
	Community Water System Wells		Rural Domestic Water Wells		Community Water System Wells		Rural Domestic Water Wells	
Level of Measurement Variable Name	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value
WELL								
Well depth	-	<0.0005	-	<0.0005	-	0.003		
Well age			+	0.013				
Wellhouse protects the well					+	0.001		

A final, puzzling, result is the association between protection of the wellhead by a wellhouse and pesticide detections at CWS wells. The result is based on positive questionnaire responses representing approximately 56 percent of CWS wells. Although well sampling teams occasionally reported the presence of stored pesticides in well houses (where well owners may keep them because they are close to a water source for mixing) no comments by field interviewers reporting such an observation were found on any questionnaire for a well where pesticides were detected.

4.2 Multivariate Analyses

EPA carried out multivariate regression analyses of numerous factors that were significantly associated with detections of analytes.[41] Section 2.2.4 explains the statistical procedures used to analyze the models presented in this section. The purpose of these analyses was to investigate the relative importance of the numerous associations and identify a combination of indicators for well contamination. Regressions were performed for the dependent variables pesticide detections, nitrate detections, and nitrate concentrations in both CWS and rural domestic wells. The 13 models presented represent the strongest results for approximately 100 variables that were considered based on results of the univariate analyses presented in Chapter 3 and Section 4.1. Results of the multivariate analyses are presented for each of the six dependent variables in the following order: Pesticide detections in CWS wells; pesticide detections in rural domestic wells; nitrate detections in CWS wells; nitrate detections in rural domestic wells; nitrate concentrations in CWS wells; and nitrate concentrations in rural domestic wells. Significance levels and standard errors are presented for estimated regression coefficients in each of the 13 models. The p-values for the coefficients indicate the relative significance of the independent variable's effect on the dependent variable, accounting for the effects of the other variables included in the model.

4.2.1 Pesticide Detections in CWS Wells

Exhibits 4-9 and 4-10 describe models for pesticide detections in CWS wells.

Exhibit 4-9

Estimated Logistic Regression Model for the Probability of Detecting at Least One Pesticide in Community Water System Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	0.90	1.02	0.376
PASTFERT	-64.26	27.07	0.018
ℓn(Well Depth)	-0.51	0.20	0.001

The variable PASTFERT measures the proportion of acres within a county that are pasture or range land on which fertilizers are used. The number of acres comes from the 1987 Census of Agriculture; county size information was gathered from the 1986 County Handbook to account appropriately for the effect of large or small counties. This is a county level measurement applied to well level data. Measurements of fertilizer use at the well sites did not produce significant predictor variables.

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[41] The multivariate analyses were performed using version 5.41 of the SUDAAN software package.

The second variable in the estimated model comes from the NPS Main Questionnaire item pertaining to well depth. A logarithmic transformation was necessary to reduce the effect of a few samples from very deep wells. Well depth is measured in feet.

The questionnaire item corresponding to presence or absence of other operating wells within 300 feet of the sampled wells can be used in place of the well depth variable without substantially reducing the model performance. That model is presented in Exhibit 4-10.

Exhibit 4-10
Alternative Estimated Logistic Regression Model for the Probability of Detecting at least One Pesticide in Community Water System Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	-2.24	0.31	0.000
PASTFERT	-71.05	27.14	0.009
Presence of Other Operating Well	0.89	0.37	0.017

4.2.2 Pesticide Detections in Rural Domestic Wells

Exhibits 4-11 and 4-12 describe models for pesticide detections in rural domestic wells.

Exhibit 4-11
Estimated Logistic Regression Model for the Probability of Detecting at Least One Pesticide in Rural Domestic Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	-1.14	0.60	0.061
CROP_VAL	0.58	0.19	0.002

The variable CROP_VAL measures sales of crops (including greenhouse and nursery crops) in $1,000, prorated by county size. The sales information comes from the 1987 Census of Agriculture. County size information was gathered from the 1986 County Handbook to account appropriately for the effect of large or small counties. This is a county level measurement applied to well level data.

Models including more predictor variables did not perform as well in general as the model containing only the CROP_VAL variable. Inclusion of a variable measuring the number of beef cows per county acre (again from the 1987 Census of Agriculture) results in a model that performs almost as well as the one presented (Exhibit 4-12). However, the BEEFCOW variable is highly negatively correlated with CROP_VAL and enters the model with marginal significance only.

Exhibit 4-12

Alternative Estimated Logistic Regression Model for the Probability of Detecting at Least One Pesticide in Rural Domestic Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	-3.53	1.36	0.011
CROP_VAL	0.61	0.21	0.004
BEEFCOW	-0.50	0.23	0.034

4.2.3 Nitrate Detections in CWS Wells

Exhibits 4-13 and 4-14 describe models for nitrate detections in CWS wells.

Exhibit 4-13

Estimated Logistic Regression Model for the Probability of Detecting Nitrate in Community Water System Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	5.67	1.35	< 0.00005
Average Monthly Precipitation	-0.45	0.10	< 0.00005
pH	-0.55	0.17	0.001
PASTFERT	-21.51	7.47	0.004

Measures of precipitation, physical properties of the well water, and pesticide use are related to nitrate detections in CWS wells. Average monthly precipitation is measured in inches and covers the 12 months prior to sampling for each well. PASTFERT was described in Section 4.2.1, and pH measures the relative acidity or basicity of the well water.

The CWS Main Questionnaire item C1 pertaining to farming on the property on which a CWS well is located can be included in an alternate multivariate model (Exhibit 4-14). However, the variable's statistical significance is comparatively low and it is highly negatively correlated with PASTFERT, suggesting that the information it contains is already partially included in the model presented in Exhibit 4-12.

Exhibit 4-14

Alternative Estimated Logistic Regression Model for the Probability of Detecting Nitrate in Community Water System Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	5.78	1.40	0.0001
Average Monthly Precipitation	–0.44	0.10	< 0.00005
PASTFERT	-22.66	8.03	0.005
pH	–0.58	0.18	0.0011
Farming on the Well Property	1.19	0.53	0.025

4.2.4 Nitrate Detections in Rural Domestic Wells

Exhibits 4-15 and 4-16 describe models for nitrate detections in rural domestic wells only.

Exhibit 4-15

Estimated Logistic Regression Model for the Probability of Detecting Nitrate in Rural Domestic Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	11.25	1.82	< 0.00005
Unlined Drainage Ditch < 1/2 mile	-1.43	0.31	< 0.00005
pH	-1.15	0.20	< 0.00005
Maximum Monthly Precipitation	-0.22	0.06	0.0004
Age of Well	0.03	0.01	0.001

Data on the presence or absence of unlined drainage ditches near the sampled wells was obtained using the Local Area Questionnaire (item 12d). Age of the wells was obtained using the Main Questionnaire information on year of construction. Maximum monthly precipitation measures the greatest precipitation in any one month during the five years prior to sampling.

The variable PASTFERT can be included in this model to provide marginal improvement in performance (p-values for the other four variables do not change substantially) (Exhibit 4-16).

Exhibit 4-16

Alternative Estimated Logistic Regression Model for the Probability of Detecting Nitrate in Rural Domestic Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	13.41	2.03	< 0.00005
Maximum Monthly Precipitation	-0.27	0.07	0.00002
Unlined Drainage Ditch < 1/2 mile	-1.53	0.33	< 0.00005
pH	-1.15	0.15	< 0.00005
Age of Well	0.03	0.01	0.0003
PASTFERT	0.33	0.15	0.031

4.2.5 Nitrate Concentrations in CWS Wells

Exhibits 4-17 and 4-18 describe models for nitrate concentrations in CWS wells. Analyses were conducted for wells with nitrate detections.

Exhibit 4-17

Estimated Linear Regression Model for the Logarithm of Nitrate Concentrations in Community Water System Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	0.59	0.33	0.0725
Maximum Monthly Precipitation	-0.07	0.02	< 0.00005
Electrical Conductivity	0.0008	0.0002	< 0.00005
Nitrogen Sales	0.12	0.03	< 0.00005
ℓn(Well Depth)	-0.12	0.03	0.0002
Moist (PDI) Drought (PDI)	-0.76 -0.26	0.20 0.16	0.0001 0.1073

Maximum monthly precipitation represents the amount of precipitation in inches per month and covers the five years prior to sampling for each well. Electrical conductivity measures the total dissolved solids (parts per million) in the well water. Nitrogen sales data comes from the 1987 Tennessee Valley Authority

NFERC/EPA database and measures the total sales in tons of nitrogen from July 1, 1986, to June 30, 1987, for the county in which each well was sampled. The sales data are prorated by county size to account appropriately for the effect of large or small counties. The well depth variable comes from the NPS Main Questionnaire item pertaining to well depth. A logarithmic transformation was necessary to counter the effect of a few extreme observations. Well depth is measured in feet.

The Palmer Drought Index (PDI) measures the extent to which counties have experienced unusual drought or moist conditions in the past year. The variable is categorized for this analysis into three categories indicating drought, normal, and moist conditions. The third condition is calculable from the variable in the model presented above due to the constraint that the sum of the three PDI coefficents must be zero (i.e., the moist indicator has a coefficient of –0.76, the drought indicator has a coefficient of –0.26, and the normal category has a coefficient of 1.02).

The variable CROP_VAL can be used in place of the nitrogen sales variable without substantially reducing the performance of the model (Exhibit 4-18).

Exhibit 4-18

Alternative Estimated Linear Regression Model for the Logarithm of Nitrate Concentrations in Community Water System Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	1.20	0.25	< 0.00005
Maximum Monthly Precipitation	–0.07	0.02	< 0.00005
Conductivity	0.0009	0.0002	< 0.00005
CROPVAL	3.23	0.70	< 0.00005
ℓn(Well Depth)	–0.11	0.03	0.0008
Moist (PDI)	–0.76	0.20	0.0002
Drought (PDI)	–0.32	0.16	0.0463

4.2.6 Nitrate Concentrations in Rural Domestic Wells

Exhibits 4-19, 4-20, and 4-21 provide models for nitrate concentrations in rural domestic wells.

The first two variables included in this model are described in previous sections. The "body of water" variable consists of a composite measure from several questions in the Local Area Questionnaire (questions 12a,b,d,g,h,i,j,k,l) and pertains to unlined, rather than lined, water bodies. The DRASTIC topography factor was measured at the second stage of the rural domestic well survey and pertains to the slope of the land in the hydrogeologic settings in which the sampled wells reside.

Exhibit 4-19

Estimated Linear Regression Model for the Logarithm of Nitrate Concentrations in Rural Domestic Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	0.54	0.34	0.117
ℓn(Well Depth)	-0.12	0.03	0.0001
CROP_VAL	0.21	0.06	0.0002
Body of Water within 1/2 mile	0.48	0.16	0.003
DRASTIC Topography Factor	0.03	0.01	0.004

The presence of bodies of water within 300 feet of the well (information obtained from the Well Observation Record question 6b) can be added to this model to provide marginal improvement in performance. (Exhibit 4-20) Also, the nitrogen sales variable described in the previous section can be used in place of the CROP_VAL variable without substantially altering model performance (Exhibit 4-21).

Exhibit 4-20

Alternative Estimated Linear Regression Model for the Logarithm of Nitrate Concentrations in Rural Domestic Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	0.51	0.35	0.155
ℓn(Well Depth)	-0.12	0.03	0.0001
CROP_VAL	0.21	0.01	0.0004
DRASTIC topography factor	0.03	0.06	0.005
Body of Water within 1/2 mile	0.51	0.17	0.003
Body of Water within 300 feet	-0.004	0.001	0.020

Exhibit 4-21

Alternative Estimated Linear Regression Model for the Logarithm of Nitrate Concentrations in Rural Domestic Wells

Independent Terms	Estimated Coefficients	Standard Error	p-value for Estimated Coefficients
Intercept	-1.38	0.49	0.006
ℓn(Well Depth)	-0.13	0.03	< 0.00005
DRASTIC topography factor	0.024	0.009	0.008
Body of Water within 1/2 mile	0.45	0.15	0.003
Body of Water within 300 feet	-0.009	0.001	< 0.00005
Nitrogen Sales	0.17	0.06	0.007

Results for the multivariate regression models identified in the Phase II analysis can be compared with multivariate models identified in the NAWWS. That study identified a model for predicting the occurrence of nitrate at or above concentrations of 3 mg/L. That model included season, the DRASTIC soil media component, well-specific vulnerability (measured with respect to the aquifer as high for surficial, low for confined, and moderate), and the percent of land within one-half mile with nitrogen fertilizer applied. NAWWS achieved similar results using the measured concentration of nitrate as the dependent variable in a multiple linear regression. In contrast to the models presented in this section, multivariate models identified in the NAWWS generally include both a use and a vulnerability component. NAWWS also concluded that no adequate linear combination of the seven DRASTIC components suitable for prediction of pesticide or nitrate occurrence could be identified. Some DRASTIC components were associated with detections.[42]

For pesticides, NAWWS sought variables that best predict the occurrence of detectable levels of herbicides. The best models contained variables for vulnerability and use.

4.3 Potentially Limiting or Confounding Factors

This section reports two analyses that were conducted to investigate phenomena that might have limited or confounded the results of the statistical studies. First, in order to evaluate whether the detections of pesticides and nitrate in the NPS were related to point sources of contamination, a review was conducted on the data pertaining to each well in which a detection occurred. The review found that detections could not be attributed to point sources. Second, to assess the constraints placed on the analysis by the effective number of detections, an analysis of the relationship of MRLs and detections was carried out, and concentration distributions for detected analytes were developed with which to estimate the presence of pesticides and nitrate at concentrations below their respective MRLs.

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[42] NAWWS Project Summary, pp. 19-20.

4.3.1 Review of Well-Specific Data

In addition to the statistical analysis of NPS questionnaire items, EPA reviewed the records for each of the wells at which a detection occurred. Each questionnaire was examined for every well with a pesticide detection. The primary objective of the review was to explore the idea that site-specific criteria such as pesticide spills or poor well construction were related to the detection. Point sources of contamination for the purpose of this review were defined as controllable factors that are affected by human participation (e.g., spills, mismanagement of chemicals) other than the normal application of pesticides within recommended label rates for their intended use.

Answers to selected individual questions, well diagrams and comments placed in the margin of questionnaires by interviewers, and sketches of the area within 300 feet of the well were examined for information that might lead to insights into the causes of contamination at that particular well. Interviewers' comments on well construction and descriptions of unusual situations near the well, such as materials stored near the well, were analyzed for data that were not part of the items specifically asked for in the questionnaires. Questionnaire items were crosschecked and property sketches reviewed to determine the distances of land features around the well (drainage ditches, septic tanks, farmland, cropland, wooded areas, buildings, other wells) that might explain site-specific well detections.

The review did not identify any situations in which a detection could be traced clearly to a point source of contamination. In one case, a pesticide manufacturing facility was identified within one-half mile of a well and in another pesticide storage was identified within 300 feet of the well pump. In both cases, however, the specific pesticides detected in the wells and the pesticides associated with the identified activities did not match.

4.3.2 Review of Effects of Detection Limits

Statistical analysis of Survey data was limited by the number of detections that were included in the analysis. In particular, a modest increase in the number of pesticide detections available for analysis might have substantially affected the findings and conclusions. The number of detections available for analysis was affected by a number of elements of the Survey design, including the number of samples collected for the survey, and the use of minimum reporting limits to achieve a high level of confidence in those detections and concentrations that were reported. The MRLs were intended to eliminate false positives, but also ensured that the number of positive detections available for analysis in Phase II was smaller than it would otherwise have been.[43] For example, the proportion of atrazine detections nationally was estimated to be 1.7% and 0.7% respectively for CWS wells and rural domestic wells. These rates of detection were too low to allow reasonable statistical analysis similar to analyses presented in this report for nitrate and the "any pesticide" group. Other studies such as the Monsanto National Alachlor Well Water Survey used much lower detection limits for atrazine and consequently reported higher detection rates.[44] It is clear that atrazine probably occurs in some wells at levels lower than its NPS MRL of 0.12 μg/L, and use of a lower detection limit would permit more data analysis than is currently possible. EPA carried out two studies to estimate the influence of MRLs on detections. The first, reported in Section 4.3.2.1, addressed the association between pesticide and nitrate detections and MRLs. The second, described in Section 4.3.2.2, involved the preparation of estimated concentration distributions for nitrate and DCPA acid metabolites, and compared the MRLs to those concentration distributions to estimate the likelihood that pesticides were present in wells at concentration levels below the MRLs for those analytes.

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[43] Support for the use of MRLs and descriptions of the procedures to be followed for establishing detection and reporting limits are provided in Glaser, J.A., D.L. Foerst, G.D. McKee, S.A. Quare, W.L. Budde, December 1981, Trace Analysis for Wastewaters, Environmental Science and Technology, 15(12), pp. 1426-1435; Keith, L.H., W. Crummett, J. Deegan, R. Libbey, J. Taylor, G. Wentler, Principles of Environmental Analysis, 55 Analytical Chemistry, 1983, pp. 2210-2218; Kirchner, C.J., Quality Control in Water Analysis, 17(4) Environmental Science and Technology, 1983, pp. 174A-181A; and Long, G.L. and J.D. Winefordner, Limit of Detection, A Closer Look at the IUPAC Definition, 55(7) Analytical Chemistry, June 1983, pp. 712A-724A. Arguments for reporting all data, with documentation of their limitations, are found in Klein, L.H., Report Results Right! Part 1, June 1991, CHEMTECH, pp. 352-356; Klein, L.H., Report Results Right! Part 2, August 1991, CHEMTECH, pp. 486-489; Porter, P.S., R.C. Ward, H.F. Bell, The Detection Limit, 22(8) Environmental Science and Technology, 1988, pp. 856-861; and Lambert, D., B. Peterson, and I. Terpenning, Non-Detects, Detection Limits, and the Probabilities of Detection, 86 Journal of the American Statistical Association, June 1991, pp. 266-277.

[44] For the Monsanto National Alachlor Well Water essentially all positive values were reported as detections; the rate of detection of atrazine was estimated to be approximately 12% for the alachlor use area as defined by Monsanto.

4.3.2.1 Analysis of Association of Detections and MRLs

EPA's analysis to examine the relationship between MRLs and detections of pesticides was carried out for the 111 quantifiable analytes. Because the analysis was chemical-specific, the Survey weights were not required. The distribution of the MRL data is heavily skewed so a logarithmic transformation was used.

Exhibit 4-22 provides summary statistics for the MRLs for the detected and non-detected groups of pesticides respectively. Although the mean MRL is greater for non-detected pesticides, the difference between the means for detected and non-detected pesticides is not statistically significant. That is, the analysis indicated that there was no significant difference between the MRLs of analytes that were detected and those that were not. The descriptive significance level associated with tests of difference between the means, transformed to the logarithmic scale, is approximately 0.1.

Exhibit 4-22

Summary Statistics for NPS MRLs by Detected and Non-Detected NPS Pesticides

Pesticide Group	Mean (µg/L)	Standard Error	Mean of the Logarithm	Standard Error
Detected	1.23	0.73	−1.21	0.52
Non-Detected	2.09	0.72	−0.54	0.13

4.3.2.2 Analysis of Relationship of MRLs to Concentration Distributions

In order to examine further the effect of MRLs on pesticide and nitrate detections in wells, EPA developed estimated concentration distributions.

The procedures followed are described in Section 2.2.4.7. Results for the concentration estimates, reported in Section 4.4.2, suggest that approximately 0.9% of rural domestic wells (95,000 wells) contain DCPA acid metabolites at concentrations below the MRL of .10 µg/L; and approximately 7.3% (770,000 wells) contain nitrate at concentrations below the MRL of .15 mg/L. Results for CWS wells suggest that 4.3% (4,000 wells) contain nitrate at concentrations below the MRL. The statistical procedure could not generate reasonable estimates for the number of CWS wells with DCPA acid metabolites below the MRL.

A comparison of the national estimates of wells containing nitrate, DCPA acid metabolites from Phase I and Phase II is presented in Exhibit 4-23. Phase I estimates are based on detections above the MRL only,

Exhibit 4-23

Estimated Number and Percent of Wells* Containing Nitrate or DCPA Acid Metabolites

Analyte	Community Water System Wells				Rural Domestic Wells			
	Phase I*		Phase II**		Phase I*		Phase II**	
Nitrate	49,300	52.1%	53,000	56.1%	5,990,000	57.0%	6,720,000	64.1%
DCPA Acid Metabolites	6,010	6.4%	—	—	264,000	2.5%	315,000	3.2%

(Based on estimated 94,600 CWS wells and 10.5 million rural domestic wells)

* Phase I estimates are based on detections above the MRL.

** Phase II estimates are based on estimated concentration distributions including concentrations below the MRL.

whereas Phase II estimates are based on the modeled distributions including concentrations below the MRLs. The modeled distributions can also be used to estimate the number of wells containing chemicals above the MRL; these estimates should be very close to the Phase I estimates but may not be exactly the same due to the modeling procedure used (see Section 2.2.4.7). Exhibit 4-23 indicates that many wells tested during the survey could contain specific pesticides or nitrate below levels the analytical laboratories could reliably quantify. It is also possible that many of the analytes not detected in the survey may be present in concentrations below their respective reporting limits.

4.4 Exposure and Risk Estimates

This section describes the results for national estimates of adult exposures to concentrations of DCPA acid metabolites and nitrate, and infant exposures to nitrate, through consumption of these compounds in drinking water drawn from community water systems and rural domestic wells sampled as part of the National Pesticide Survey (NPS). Estimates have also been made of the populations exposed to at least one pesticide and to at least one pesticide above health-based levels. These estimates are based on procedures similar to those used to produce estimates for the NPS Phase I Report.

The results of the exposure and risk analyses are presented in the following sections. Section 4.4.1 presents estimates of the concentration distributions for nitrate and DCPA acid metabolites for rural domestic wells and for community water system wells. Section 4.4.2 presents the corresponding population exposure and risk estimates for the analytes in each survey. The major findings of these analyses are summarized in Section 4.4.3.

As a result of Survey design constraints and the limitations of the available NPS data, the exposure and risk estimates developed in this exercise must be viewed with caution. The NPS was designed to be a national, statistical study of the occurrence of pesticides and nitrate in public and private drinking water wells. The Survey was not designed to provide estimates of population exposure and risk. The development of exposure and risk estimates is further complicated by the small number of detections for all NPS analytes except nitrate. The two analytes included in the development of concentration distributions and resultant exposure and risk estimates are those with the highest frequency of detection in the NPS. A large number of assumptions had to be made in the development of these estimates. The reader is strongly encouraged to carefully review these assumptions, which are summarized in Sections 2.2.4.7 and 2.2.4.8, and note that proper interpretation of the results presented in this section can only be made in light of these caveats.

4.4.1 Concentration Distributions

Estimates of the distribution of concentration of nitrate and DCPA acid metabolites for rural domestic wells and for community water systems are presented in this section. The estimated distributions are summarized by the following three parameters (see Section 2.2.4.7 for a detailed discussion of statistical procedures):

π	The probability of non-occurrence;
μ	The mean of the ℓn(concentrations) given occurrence; and
σ	The standard deviation of the ℓn(concentrations) given occurrence.

Assuming that the concentrations of analytes in contaminated wells follow a lognormal (μ,σ) distribution, the ℓn(concentrations) follow a normal distribution with mean μ, and standard deviation σ. In the following exhibits, estimates of the three defining parameters of the estimated concentration distributions, π, μ, and σ, are presented along with estimates for medians and means of the distributions. Confidence intervals are also presented.

Exhibit 4-24 presents a national concentration distribution of nitrate in rural domestic wells.

Exhibit 4-24

Estimates of the Nitrate Concentration Distribution for Rural Domestic Wells

Parameter	Estimate	95% Confidence Interval	
		Lower Bound	Upper Bound
π	35.9%	30.7%	43.5%
μ	0.04	-0.30	0.28
σ	1.49	1.31	1.68
median concentration	0.31 mg/L	0.18 mg/L	0.48 mg/L
mean concentration	2.00 mg/L	1.60 mg/L	2.56 mg/L
95th percentile	8.47 mg/L	6.87 mg/L	10.72 mg/L
99th percentile	26.00 mg/L	19.85 mg/L	34.73 mg/L
median given occurrence	1.04 mg/L	0.74 mg/L	1.32 mg/L
mean given occurrence	3.09 mg/L	2.53 mg/L	3.91 mg/L

As Exhibit 4-24 demonstrates:

- Approximately 64% of rural domestic wells contain nitrate (the parameter π represents the probability of non-occurrence and shows that approximately 36% do not contain nitrate);
- Approximately 7.3% of rural domestic wells (770,000 wells) are estimated to contain nitrate at concentrations below the minimum reporting limit.

- The median concentration of nitrate in all rural domestic wells is approximately 0.3 mg/L. The mean concentration is approximately 2.0 mg/L;

- The median concentration of nitrate in rural domestic wells in which nitrate occurs is approximately 1.0 mg/L. The mean concentration in those wells is approximately 3.1 mg/L; and

- In the NPS Phase I Report, EPA estimated that approximately 2.4% of rural domestic wells (254,000 wells) contain nitrate above the MCL of 10 mg/L.[45] The corresponding estimate from the estimated lognormal model used in the Phase II analysis is 4.0% (with 95% confidence bounds of 3.0% and 5.4%).

In addition to these results for well concentrations, the estimated proportion of wells containing nitrate at concentrations greater than the minimum reporting limit of 0.15 mg/L is 56.8% compared to an estimated 57.0% developed in Phase I.[46]

The estimated concentration distribution of nitrate in rural domestic wells is presented graphically in Exhibit 4-25. The proportion corresponding to non-occurrence is not included on the graph; consequently the probability area encompassed by the graph is approximately 64.1% (i.e., $1-\pi$). The graph shows that the mode of the distribution, given occurrence, is close to the MRL for nitrate of 0.15 mg/L.

Exhibit 4-26 presents a national concentration distribution of DCPA acid metabolites in rural domestic wells. As Exhibit 4-26 demonstrates:

- Approximately 3% of rural domestic wells contain DCPA acid metabolites;[47]

- Approximately 0.6% of rural domestic wells (63,000 wells) are estimated to contain DCPA acid metabolites at concentrations below the minimum reporting limit of 0.1 μg/L.

- The median concentration of DCPA acid metabolites in rural domestic wells in which it occurs is approximately 0.29 μg/L. The mean concentration of DCPA acid metabolites in these wells is approximately 0.43 μg/L.

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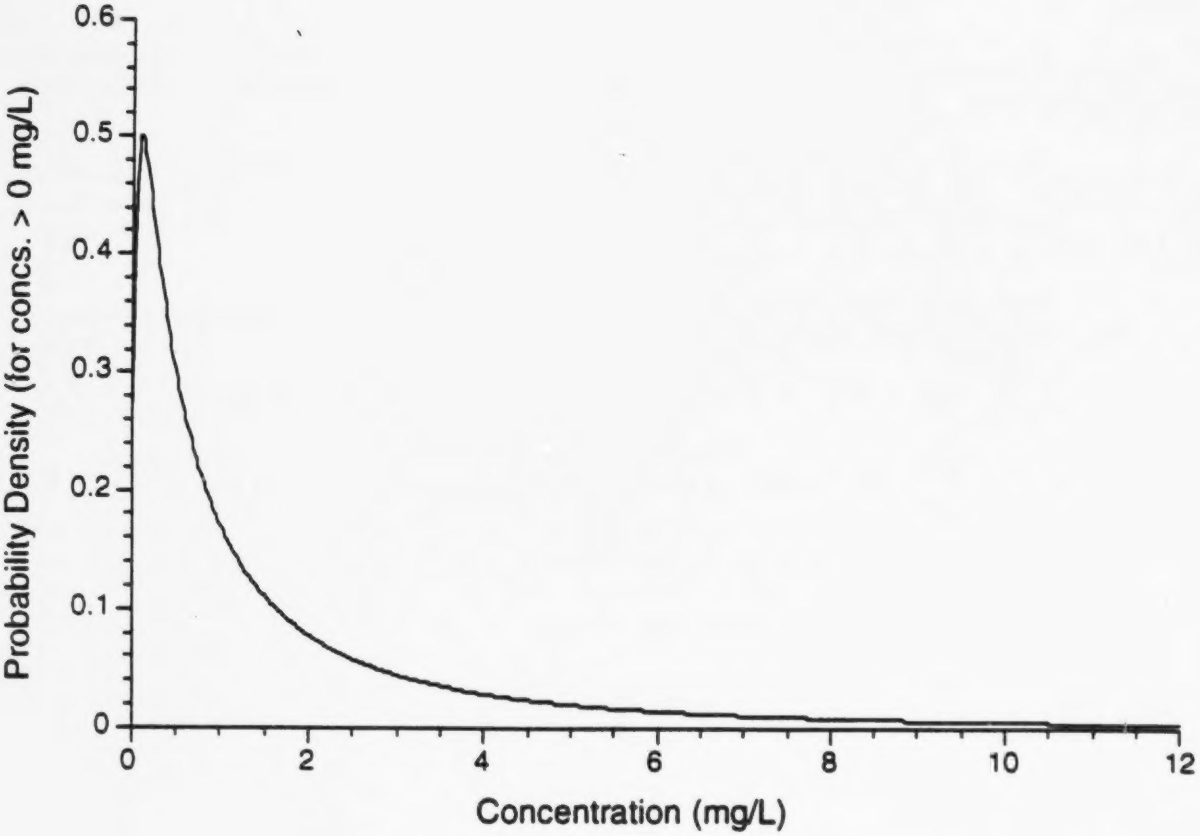
[45] National Survey of Pesticides in Drinking Water Wells, Phase I Report, EPA 570/9-90-015, November 1990, p. 66. The 95% confidence interval bounds are 1.2% and 4.4%.

[46] The 95% confidence interval lower and upper bounds of the 56.8% estimate are 51.3% and 62.8%. The 95% confidence interval bounds of the 57.0% estimate are 50.3% and 63.8%.

[47] The 40 re-samples used to develop this estimate yielded two distinct sets of results. The first set, consisting of 38 of the 40 re-samples, estimates the probability of non-occurrence to be approximately 97%; the second set estimates the same parameter to be 0%. The problem for the second set is that the re-samples contain positive data that does not allow the maximum likelihood estimation procedure to converge to reasonable estimates. For these two re-samples, the maximum likelihood procedure is unable to distinguish between non-occurrence and occurrence at very low levels (e.g., 10^{-10} μg/L). Reporting the median, as opposed to the mean, of the re-sample estimates reduces the effect of these two re-sample values on the reported estimates, but the lower confidence bound is largely based on the re-sample values. Although the maximum likelihood estimation procedure is unable to distinguish between non-occurrence and occurrence at very low levels, the effect on estimates of percentiles in the right tail of the distribution (i.e., higher concentrations) is not as pronounced.

Exhibit 4-25

Estimated Distribution of Nitrate Concentration in Rural Domestic Drinking Water Wells*



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* The estimated distribution is the conditional probability for wells containing nitrate only. The estimated proportion of all rural domestic wells in which nitrate occurs is approximately 64.1% (corresponding approximately to 6,740,000 rural domestic wells). The MCL for nitrate is 10 mg/L. Nitrate occurs above this level in approximately 425,000 rural domestic wells.

Exhibit 4-26

Estimates of the DCPA Acid Metabolites Concentration Distribution for Rural Domestic Wells*

Parameter	Estimate		
		Lower Bound	Upper Bound
π	97.0%	0.00%	99.2%
μ	-1.23	-7.90	-0.19
σ	1.24	0.38	2.80
median concentration	0 μg/L	0 μg/L	0.000 μg/L
mean concentration	0.017 μg/L	0.007 μg/L	0.034 μg/L
95th percentile	0 μg/L	0 μg/L	0.04 μg/L
99th percentile	0.407 μg/L	0.143 μg/L	0.82 μg/L
median given occurrence	0.29 μg/L	0.00 μg/L	0.83 μg/L
mean given occurrence	0.53 μg/L	0.02 μg/L	1.13 μg/L

* Concentrations entered as 0 imply non-occurrence. Entries of 0.00 imply occurrence at very low levels.

The estimated proportion of wells containing DCPA acid metabolites at concentrations greater than the minimum reporting limit of 0.1 μg/L is 2.4%, compared to an estimate of 2.5% generated in Phase I.[48]

The estimated concentration distribution of DCPA acid metabolites in rural domestic wells is presented graphically in Exhibit 4-27. The probability area encompassed by the graph is approximately 3%, corresponding to the estimated proportion of occurrence of DCPA acid metabolites in rural domestic wells nationally. This graph shows that the mode of the distribution, given occurrence, is below the MRL of 0.1 μg/L for DCPA acid metabolites.

Exhibit 4-28 presents a national concentration distribution of nitrate in CWS wells. As Exhibit 4-28 demonstrates:

- Approximately 56% of CWS wells contain nitrate;
- Approximately 4.4% of CWS wells (4,000 wells) are estimated to contain nitrate at concentrations below the minimum reporting limit of 0.15 mg/L.
- The median concentration of nitrate in CWS wells is approximately 0.2 mg/L. The mean concentration is approximately 1.5 mg/L; and
- The median concentration of nitrate in CWS wells in which nitrate occurs is approximatley 1.0 mg/L. The mean concentration in those wells is approximately 2.6 mg/L.

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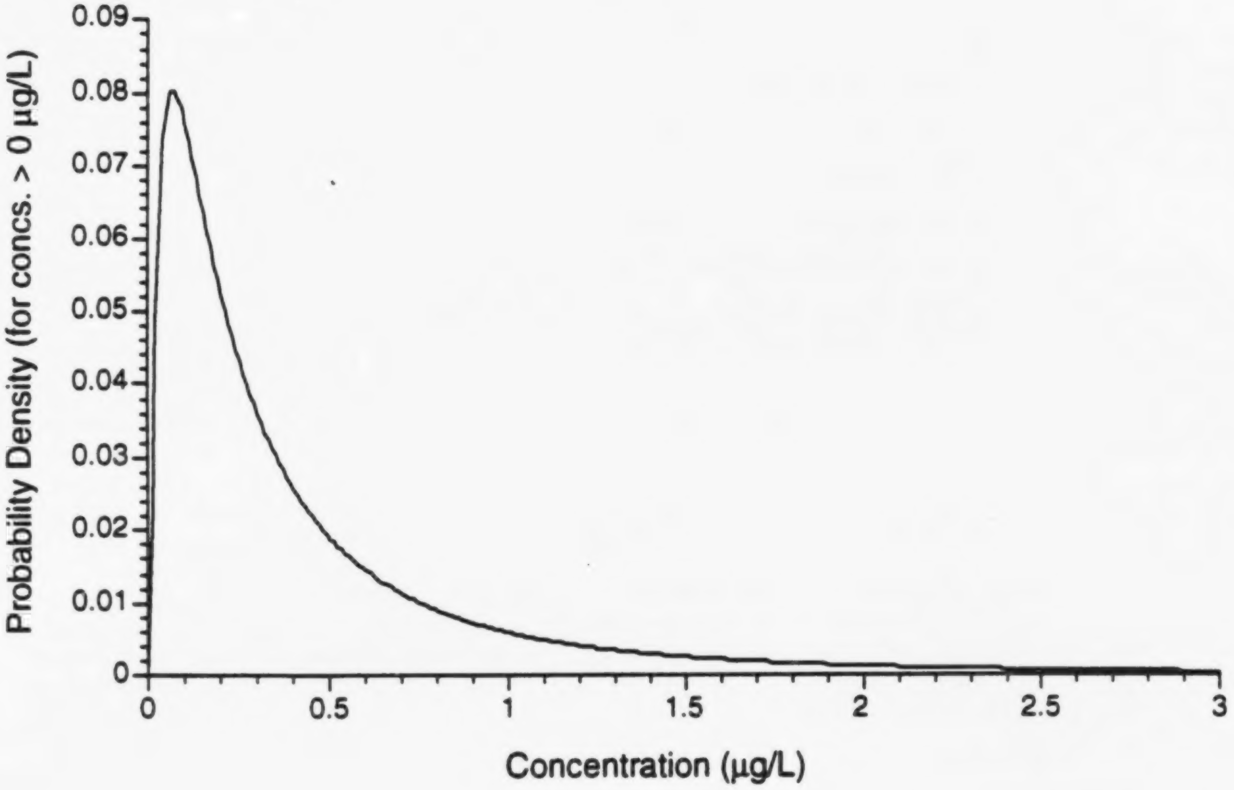
[48] The 95% confidence interval lower and upper bounds for the Phase II estimates are 0.7% and 3.4% respectively. The 95% bounds for the Phase I estimates are 1.2% and 4.5%.

Exhibit 4-27

Estimated Distribution of DCPA Acid Metabolites Concentration in Rural Domestic Drinking Water Wells*



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* The estimated distribution is the conditional probability for wells containing DCPA acid metabolites only. The estimated proportion of all rural domestic wells in which DCPA acid metabolites occur is approximately 3.3% (corresponding approximately to 338,000 rural domestic wells). The MCL for DCPA acid metabolites is 4,000 µg/L. DCPA acid metabolites were found only at much lower levels in rural domestic wells.

Exhibit 4-28

Estimates of the Nitrate Concentration Distribution for Community Water System Wells

Parameter	Estimate	95% Confidence Interval	
		Lower Bound	Upper Bound
π	43.6%	36.8%	49.8%
μ	0.02	-0.25	0.36
σ	1.35	1.13	1.52
median concentration	0.21 mg/L	0.11 mg/L	0.33 mg/L
mean concentration	1.46 mg/L	1.20 mg/L	1.75 mg/L
95th percentile	6.48 mg/L	5.28 mg/L	7.63 mg/L
99th percentile	17.57 mg/L	13.26 mg/L	22.09 mg/L
median given occurrence	1.02 mg/L	0.78 mg/L	1.44 mg/L
mean given occurrence	2.61 mg/L	2.13 mg/L	3.13 mg/L

The estimated proportion of CWS wells containing nitrate at concentrations greater than the minimum reporting limit of 0.15 mg/L is 52.0%, which parallels an estimate of 52.1% obtained in Phase I.[49]

The estimated distribution for nitrate concentrations in CWS wells is presented graphically in Exhibit 4-29. The proportion corresponding to non-occurrence of nitrate in CWS wells (approximately 43.6%) is not included in this representation. The graph shows that the mode of the concentration distribution, given occurrence, is approximately 0.3 mg/L.

Exhibit 4-30 presents the estimated distribution of DCPA acid metabolite concentrations in CWS wells. As Exhibit 4-30 demonstrates, the estimation procedure failed to distinguish between non-occurrence and occurrence at very low levels (e.g., 10^{-10} μg/L).[50] Consequently, the estimated proportion of wells that contain DCPA acid metabolites is estimated to be 100%, but CWS wells are expected to contain DCPA acid metabolites at extremely low levels as indicated by the median value of 0.003 μg/L. Although the method used does not appear to provide a good model of DCPA acid metabolites concentrations near zero, it does provide more reasonable estimates for the mean and median of the distribution and for the higher quantiles presented. For example, the estimated proportion of wells containing DCPA acid metabolites above its MRL of 0.1 μg/L is 9.1% compared to a value of 6.4% determined in Phase I.[51]

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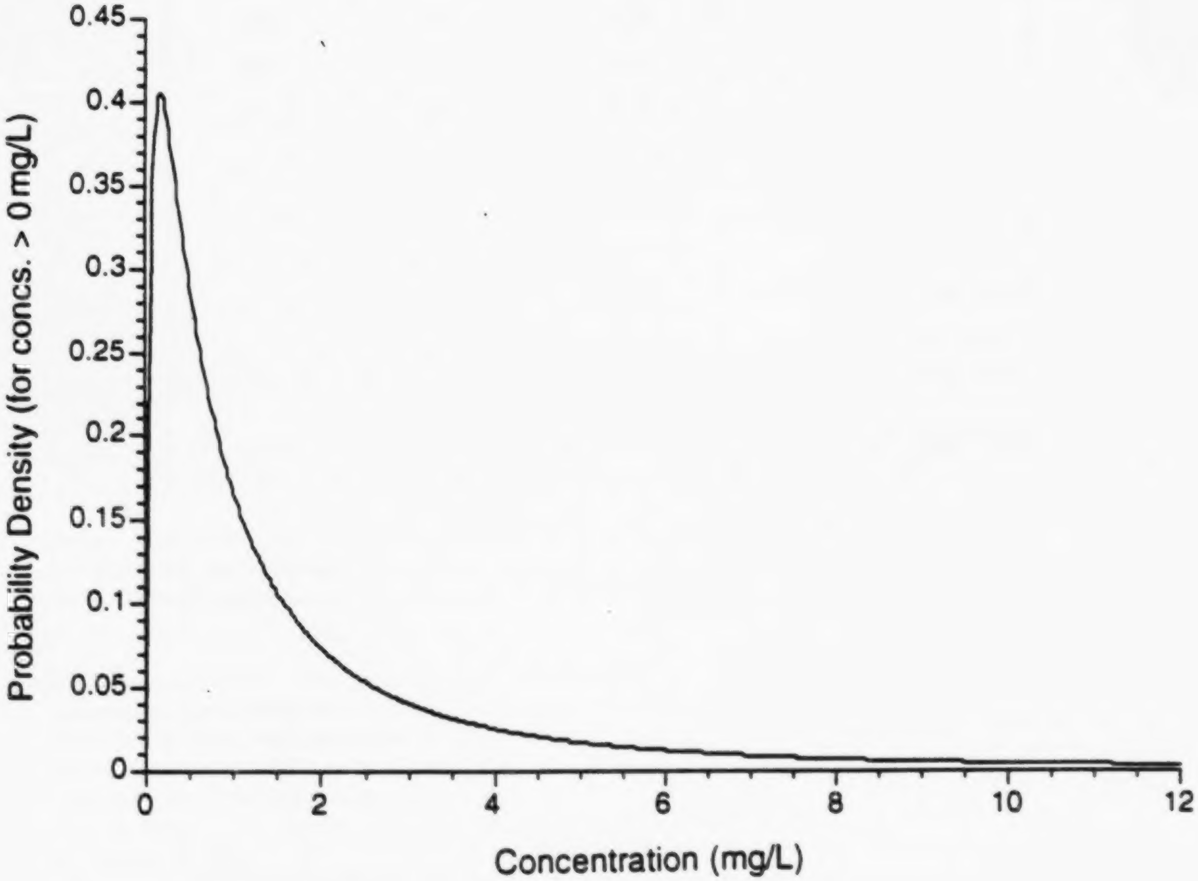
[49] The 95% confidence interval lower and upper bounds for the Phase II estimate are 47.8% and 56.1% respectively. For the Phase I estimate the bounds are 48.8% and 56.3%.

[50] The 40 re-samples used to develop the estimates presented in Exhibit 4-29 yielded 37 estimated models for which the probability of occurrence was 100%. For eight of the 37 re-samples the maximum likelihood procedure did not converge fully. The estimated models for these 8 resamples are based on partial convergence only. The effect of including these 8 estimated models to produce bootstrap estimates is not likely to be pronounced because of their similarity to most of the other re-sample estimated models.

[51] The 95% confidence interval lower and upper bounds for the Phase II estimates are 6.3% and 14.5%. For the Phase I estimates the bounds are 3.4% and 9.3%.

Exhibit 4-29

Estimated Distribution of Nitrate Concentration in Community Water System Wells*



- The estimated distribution is the conditional probability for wells containing nitrate only. The estimated proportion of all CWS wells in which nitrate occurs is approximately 56.4% (corresponding approximately to 53,300 CWS wells). The MCL for nitrate is 10 mg/L. Nitrate occurs above this level in approximately 2,500 CWS wells.

Exhibit 4-30

Estimates of the DCPA Acid Metabolites Concentration Distribution for Community Water System Wells

Parameter	Estimate		
		Lower Bound	Upper Bound
π	0.0%	0.00%	88.7%
μ	-5.69	-6.66	-1.48
σ	2.65	1.75	3.20
median concentration	0.003 μg/L	0 μg/L	0.016 μg/L
mean concentration	0.11 μg/L	0.05 μg/L	0.23 μg/L
95th percentile	0.25 μg/L	0.16 μg/L	0.34 μg/L
99th percentile	1.62 μg/L	0.65 μg/L	2.85 μg/L
median given occurrence	0.003 μg/L	0.001 μg/L	0.23 μg/L
mean given occurrence	0.12 μg/L	0.05 μg/L	1.08 μg/L

The estimated distribution of concentrations of DCPA acid metabolites for CWS wells is presented graphically in Exhibit 4-31. As the concentration approaches zero, the probability density function value becomes very large. The graph portrays the entire probability distribution (except for the right tail which contains close to zero probability) since the estimated probability of non-occurrence of DCPA acid metabolites in CWS wells is 0%. Exhibit 4-30 demonstrates the mathematical procedure's inability to distinguish between non-occurrence and occurrence at very low concentrations.

4.4.2 Goodness-of-Fit of the Estimated Concentration Distributions

Goodness-of-fit analysis of the estimated concentration distributions was accomplished by comparing quantiles of the estimated distribution to quantiles of the empirical (observed) distribution. Two approaches were taken for this comparison. The first was to calculate both sets of quantiles[52] from the observed data, and to plot the two sets of quantiles against one another. If the estimated distribution provides an exact fit for the data then the points of the quantile-quantile plot should fall on a straight line with slope 1. The extent to which these points do not fall on a straight line indicates how poorly the data are fit by the estimated distribution.

The results of the quantile-quantile plots were promising, but they provide too little information about the tail of the estimated distribution (high concentrations), because no matter how discrepant the estimated distribution may be from the data, quantiles near 100% will fall close to the straight line of slope 1. The percentage change in quantile values may be a more relevant measure of goodness-of-fit for extreme concentrations.

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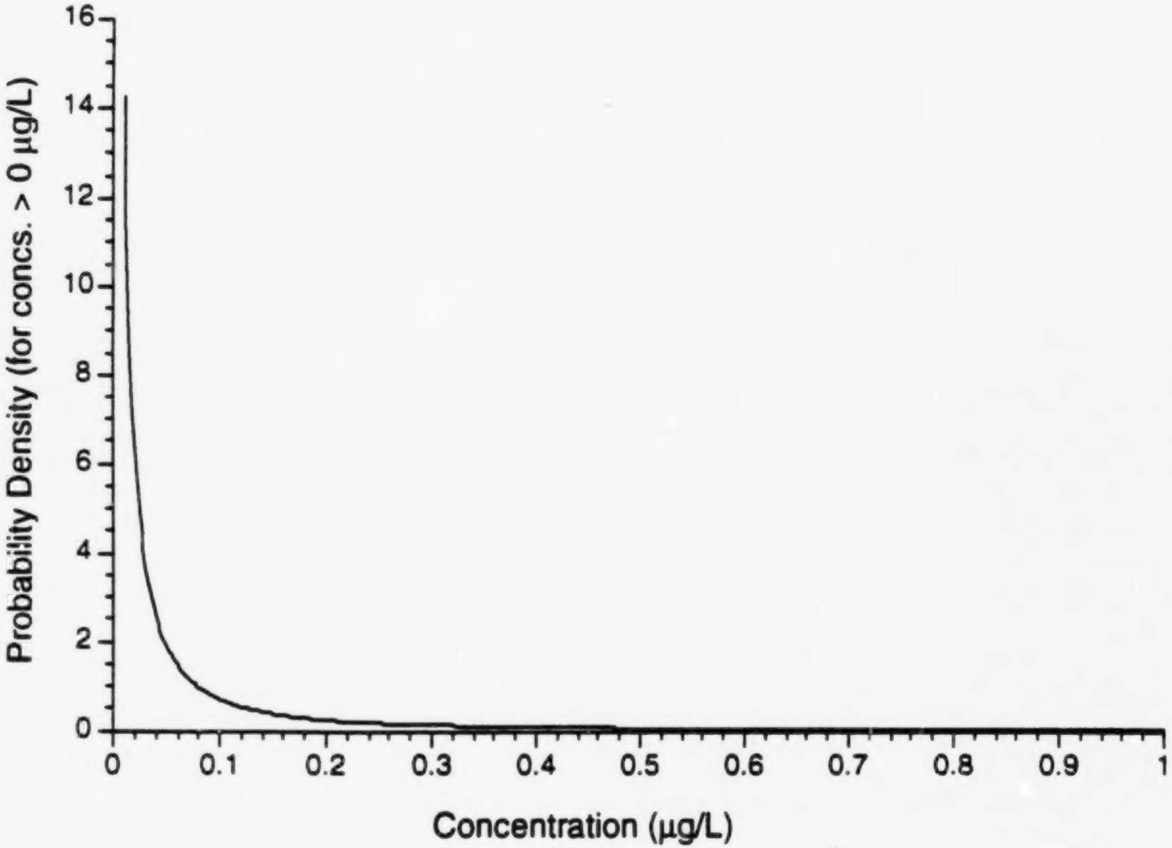
[52] The term quantile is used in this section as opposed to the term percentile used in other sections of this chapter. Quantile is the term more applicable when exact percentiles are not being used (e.g. the 95th percentile is the 0.95 quantile, but the 0.951 quantile is not often referred to as the 95.1 percentile).

Exhibit 4-31

Estimated Distribution of DCPA Acid Metabolites Concentration in Community Water System Wells*



- According to the estimated distribution, DCPA acid metabolites occur in all CWS wells, although the concentration is extremely small (less than 0.05 μg/L) in most CWS wells. The MCL for DCPA acid metabolites is 4,000 μg/L. DCPA acid metabolites were found only at much lower levels in CWS wells.

The second approach was adopted to better assess goodness-of-fit for high concentrations. The observed concentrations were plotted against predicted concentrations, where predicted concentrations were calculated through a two step process involving both sets of quantiles. Initially quantiles were calculated for each data point (positive concentration) from the empirical distribution using the survey weights. Then the concentration corresponding to the same quantile of the estimated distribution was calculated. Plots of the observed versus predicted values determined in this way should also fall on a straight line if the estimated distribution models the data perfectly. The advantage of this method is that the range of the plot is not limited for high concentrations, which makes an assessment of goodness-of-fit for these values more viable.

Exhibit 4-32 shows the quantile-based, predicted versus observed data plot for nitrate concentrations in rural domestic wells. Whereas the estimated distribution models the data well at low concentrations (where much of the data is contained), it does not model the data well at higher concentrations. Exhibit 4-32 is typical of the predicted versus observed data plots generated for concentration distributions in the Phase II analysis. The estimated distributions model comparatively low concentrations well, but do not model high concentrations, where there is far less information or data, very well. Consequently, estimates presented in this chapter concerning high concentrations at high quantiles should be treated with more caution than estimates at more likely concentration levels. Although estimates at extremely high concentrations are less accurate, the estimates of the number of wells containing nitrate above the MCL (10 mg/L) are reliable.

4.4.3 Population Exposure and Risk Estimates

In this section, results are presented for estimates of national population exposure, and resultant health risks, due to nitrate and DCPA acid metabolites for rural domestic wells and for community water systems. Estimates are provided of the populations corresponding to quantiles of general interest (e.g., 95th and 99th percentiles), and of the number of individuals exposed above health-based levels. Percentiles and concentration values corresponding to health levels of concern are presented in Exhibits 4-33 through 4-37. Confidence intervals are also presented.

The results presented in this section are based on the following population estimates:

- Approximately 30,300,000 people drink ground water from rural domestic wells nationally. Approximately 450,000 of these people are infants under the age of one year;

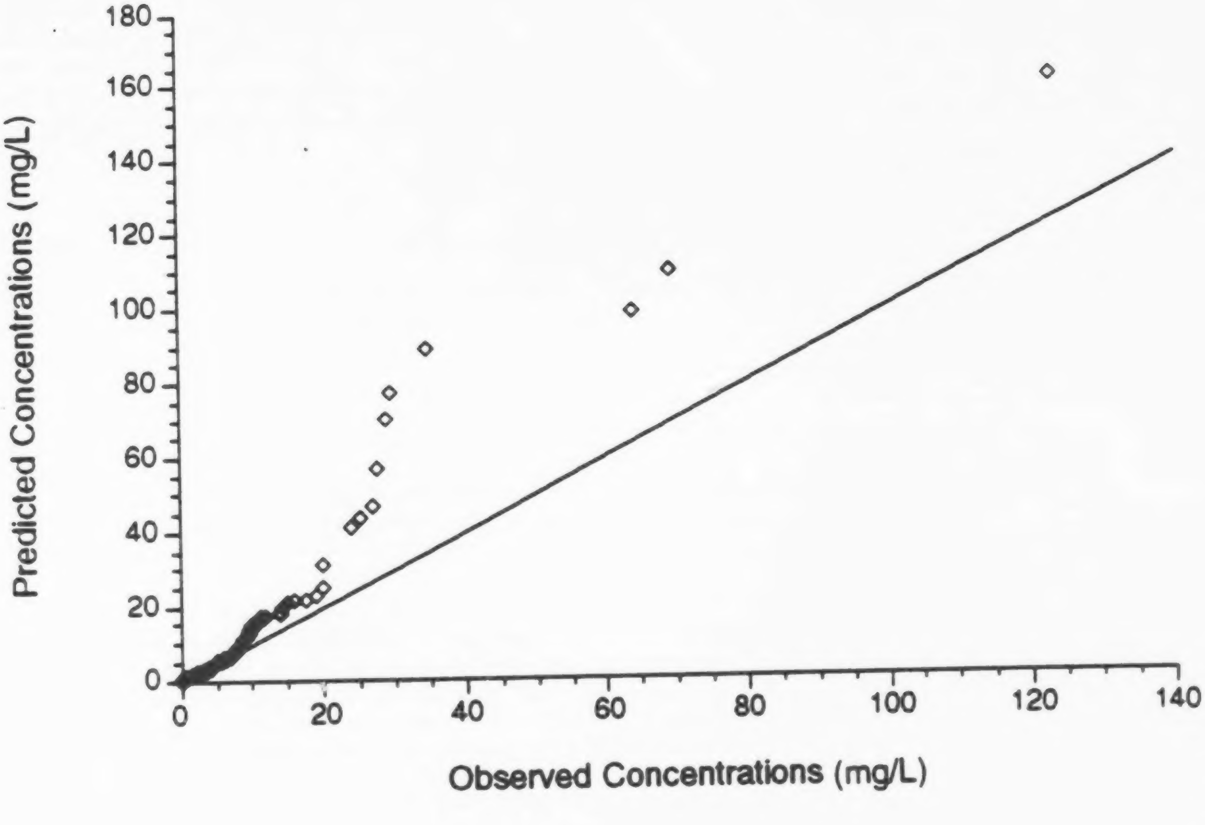
- Approximately 136,000,000 people drink ground water from CWS wells nationally. Approximately 2,000,000 of these people are children under the age of one year;

- There are approximately 10,500,000 rural domestic wells nationally, 9,900,000 of which provide ground water for drinking. On average, each rural domestic drinking water well that provides ground water for drinking serves approximately 3.1 people; and

- There are approximately 94,600 wells in 35,800 community water systems that provide ground water for drinking. On average, each system consists of approximately 2.6 wells.

Exhibit 4-32

Plot of Predicted Versus Observed Nitrate Concentrations in Rural Domestic Wells



Exhibits 4-33 and 4-34 present estimates at various concentration levels of the number of people exposed to nitrate from rural domestic wells.

- More than one and a half million people are estimated to drink water from rural domestic wells that contain at least 10 mg/L nitrate (with an upper bound 95% confidence interval of 11.8 million persons and a lower bound estimate of 8.02 million). Of the people exposed to nitrate above this level, approximately 22,500 are expected to be infants. The health risk posed by nitrate at concentrations at or above 10 mg/L, particularly if the water is also contaminated with bacteria, is a condition known as methemoglobinemia. Infants are at most risk of developing this condition. The Maximum Contaminant Level (MCL) for nitrate is 10 mg/L;

- The median nitrate concentration to which people who drink ground water from rural domestic wells are exposed is approximately 0.32 mg/L; and

- Approximately 19.2 million people drink water from rural domestic wells that contain nitrate.

Exhibit 4-33

Estimates of Population Exposed to Nitrate in Rural Domestic Wells by Distribution Percentile

Percentile	People Exposed	Concentration (mg/L)	95% Confidence Interval	
			Lower Bound (mg/L)	Upper Bound (mg/L)
Median	15,100,000	0.32	0.20	0.47
95	1,510,000	10.1	8.02	11.8
99	303,000	31.5	22.3	40.9

Exhibit 4-34

Estimates of Population Exposed to Nitrate by Concentration in Rural Domestic Wells

Concentration (mg/L)	Population Exposed	95% Confidence Interval	
		Lower Bound	Upper Bound
All concentrations > 0	19,200,000	17,800,000	21,800,000
≥ 10	1,530,000	1,140,000	1,820,000

Exhibits 4-35 and 4-36 present estimates of the number of people exposed to nitrate in CWS wells.

- Approximately 3 million people drink water from CWS wells that contain nitrate at a concentration of at least 10 mg/L, the maximum contaminant level (MCL) for nitrate. Of the people exposed to nitrate above this level, approximately 43,500 are expected to be infants at possible risk of developing methemoglobinemia, particularly if the water is also contaminated with bacteria.

Exhibit 4-35

Estimates of Population Exposed to Nitrate in Community Water System Wells by Distribution Percentile

Percentile	People Exposed	Concentration (mg/L)	95% Confidence Interval	
			Lower Bound (mg/L)	Upper Bound (mg/L)
Median	68,000,000	0.63	0.45	0.95
95	6,800,000	6.52	5.34	7.60
99	1,360,000	14.2	10.6	17.7

Exhibit 4-36

Estimates of Population Exposed to Nitrate by Concentration in Community Water System Wells

Concentration (mg/L)	Population Exposed	95% Confidence Interval	
		Lower Bound	Upper Bound
All concentrations > 0	85,300,000	78,100,000	98,900,000
≥ 10	2,980,000	1,600,000	4,260,000

- Approximately 85 million people drink water from community water system wells that contain nitrate; and
- The median nitrate concentration to which people in the United States are exposed is approximately 0.63 mg/L.

Exhibit 4-37 shows the estimated concentration of DCPA acid metabolites corresponding to the 99th percentile of the estimated concentration distribution for people who drink well water from rural domestic wells. The exhibit indicates that one percent of the population (303,000 people) served by rural domestic wells are exposed to DCPA acid metabolites at concentrations above 0.33 μg/L. Other percentiles, such as the median and 95th percentile, are not shown because they correspond to non-occurrence of DCPA acid metabolites in rural domestic wells. (Consequently, the estimate of the percent of people exposed to DCPA acid metabolites from rural domestic wells is less than 5%.) Exhibit 4-37 shows the 99th percentile of the concentration for DCPA acid metabolites. The number of persons exposed at lower concentrations are not shown (see footnote 43).

Exhibit 4-37

Estimate of Population Exposed to DCPA Acid Metabolites in Rural Domestic Wells at 99th Percentile

Percentile	People Exposed	Concentration (µg/L)	95% Confidence Interval	
			Lower Bound (µg/L)	Upper Bound (µg/L)
99	303,000	0.33	0.11	0.78

NPS estimates that no individuals served by rural domestic wells are exposed to DCPA acid metabolites at concentrations above those corresponding to the lifetime Health Advisory Level of 4,000 µg/L. Therefore, no adverse health effects are expected in this population as a result of exposure to DCPA acid metabolites in drinking water. As Exhibit 4-38 indicates, approximately 1.2 million people are estimated to drink water from rural domestic wells that contain DCPA acid metabolites (with an upper 95% confidence bound of 30.3 million and a lower bound of 0.4 million).[53]

Exhibit 4-38

Estimates of Population Exposed to DCPA Acid Metabolites by Concentration in Rural Domestic Wells

Concentration (µg/L)	Population Exposed	95% Confidence Interval	
		Lower Bound	Upper Bound
All concentrations > 0	1,230,000	460,000	30,300,000
≥ 4,000	0	0	0

Exhibits 4-39 and 4-40 present estimates of the number of people exposed to DCPA acid metabolites in CWS wells.

- No individuals served by community water systems are exposed to DCPA acid metabolites at levels above those corresponding to the lifetime Health Advisory Level of 4,000 µg/L. Therefore, no adverse health effects are expected in this population as a result of exposure to DCPA acid metabolites in drinking water; and

- EPA estimates that approximately 9.4 million people drink water from community water system wells that contain DCPA acid metabolites.

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[53] The upper confidence limit is affected by the 5 re-samples that resulted in an estimate of the proportion of people exposed to be close to 100%. Two of the 5 re-samples provided data for which the maximum likelihood estimation procedure did not converge. These two estimated models may provide inaccurate estimates, although their effect on the upper confidence intervals is likely to be more pronounced than their effect on the maximum likelihood estimates presented. The lack of convergence for any of the re-samples brings into question the appropriateness of the modeling procedure. Possible explanations are that the lognormal/binomial mixture model is not appropriate, or that the number of detections is too few to be able to properly estimate the model.

Exhibit 4-39

Estimates of Population Exposed to DCPA Acid Metabolites in Community Water System Wells by Distribution Percentile

Percentile	People Exposed	Concentration (µg/L)	95% Confidence Interval	
			Lower Bound (µg/L)	Upper Bound (µg/L)
95	6,800,000	0.23	0.00	0.42
99	1;360,000	0.99	0.48	1.80

Exhibit 4-40

Estimates of Population Exposed to DCPA Acid Metabolites by Concentration in Community Water System Wells

Concentration (µg/L)	Population Exposed	95% Confidence Interval	
		Lower Bound	Upper Bound
All concentrations > 0	9,430,000	5,880,000	12,500,000
≥ 4,000	0	0	0

Exhibits 4-41 and 4-42 present estimates of numbers of wells containing at least one pesticide above health-based levels and estimates of populations exposed to at least one pesticide above the NPS MRLs and to at least one pesticide above health-based levels. These estimates are not based on concentration models, but on the estimates of populations served and the number of sampled wells containing pesticides. The estimates and confidence intervals result from the application of the sample design through the sample weights to appropriate sample statistics. The estimates are the weighted sum of the sample statistics. The formulas for calculating the estimates and confidence intervals are presented in the NPS Phase I Report.[54]

As Exhibit 4-41 shows, EPA estimates, based on the upper 95% confidence bounds for the estimates of wells containing pesticides at concentrations exceeding health-based limits, that a maximum of 7.3 percent of CWS wells and 28.3 percent of rural domestic wells that contain detected pesticides exceed the maximum contaminant level (MCL) or Lifetime Health Advisory Level (HAL) for those chemicals for which an MCL or HAL has been established. These estimates are influenced by the following critical factors: (1) less than 50% of NPS analytes have a health-based standard (see the NPS Phase I Report for a more detailed discussion of this issue); and (2) some of the pesticides and pesticide degradates may not have been detected because their MRLs were relatively high.

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[54] NPS Phase I Report, Appendix B, pp. B-52 to B-62.

Exhibit 4-41

Estimates of Percentages of Wells and Number of Wells Containing At Least One Pesticide Above Health-Based Levels

Percentage and Number of Wells with Concentration Above Health-Based Standard	CWS Wells			Rural Domestic Wells		
		95% Confidence Interval			95% Confidence Interval	
	Mean Proportion	Lower Bound	Upper bound	Mean Proportion	Lower Bound	Upper bound
% of Wells	0%	0%	7.3%	13.7%	3.4%	28.3%
Number of Wells	0%	0	700	60,000	15,000	125,000

Exhibit 4-42

Estimates of Population Exposed to Pesticide Above Reporting and Health-Based Levels

	Population Exposed					
		95% Confidence Interval			95% Confidence Interval	
Concentration	CWS Wells	Lower Bound	Upper Bound	Rural Domestic Wells	Lower Bound	Upper Bound
Above MRL	14.0 million	7.4 million	22.4 million	1.27 million	690,000	2.01 million
Above Health-Based Standard	0	0	31.5 million	150,000	12,000	450,000

4.4.4 Major Findings

The following are the major findings of this analysis of exposure and risk for populations served by rural domestic wells and community water systems:

- About 1.5 million people served by rural domestic wells are estimated to be exposed to nitrate above the Maximum Contaminant Level/Lifetime Health Advisory Level of 10 mg/L. Included in this group are approximately 22,500 infants under one year old exposed to a concentration of greater than 10 mg/L. Persons with high levels of nitrate in their private wells should consult their pediatricians and may wish to obtain water from alternate sources that have less than 10 mg/L of nitrate to help protect infants from this risk. Physicians are usually well informed about the risks to infants of high levels of nitrate in drinking water and are able to provide medical treatment.

- About 3 million people served by CWS wells are estimated to be exposed to nitrate above 10 mg/L (ppm). Included in this group are approximately 43,500 infants under one year old exposed to a concentration of greater than 10 mg/L. Public water supplies that violate the Maximum Contaminant Level of 10 mg/L for nitrate are required to notify their customers about the violation, and the adverse health effects caused by nitrate. (40 CFR 141.32) Local and state health authorities are the best source for information concerning alternate sources of drinking water for infants. Systems that apply for variances or exemptions while in violation of the standard may be required by the state to provide bottled water or point-of-use or point-of-entry devices to avoid unreasonable risks to health. (40 CFR 141.62(f))

- About 1.2 million people are estimated to be exposed to DCPA acid metabolites through consumption of drinking water obtained from rural domestic wells. About 9.4 million people are estimated to be exposed to DCPA acid metabolites through consumption of drinking water obtained from CWS wells. However, the concentrations to which these individuals are estimated to be exposed are much lower than health-based levels. Therefore, no adverse health impacts are expected as a result of this exposure, based on currently available information on the health effect from exposure to DCPA and its acid metabolites.

- An estimated 1.27 million people served by rural domestic wells are exposed to at least one pesticide above NPS minimum reporting limits (MRL). An estimated 150,000 people served by rural domestic wells are exposed to at least one pesticide above health-based levels.

- An estimated 14 million people served by CWS wells are exposed to at least one pesticide above a minimum reporting limit (MRL). However, the concentrations to which these individuals are estimated to be exposed are lower than health-based levels.

- The use of MRLs in the NPS had a significant effect on the estimates of frequency of occurrence for some analytes. Environmental contaminants tend to occur with higher frequencies at lower concentrations. Estimates of frequency of occurrence in rural domestic wells increased from those presented in the NPS Phase I Report, which were based only on concentrations above the MRL, for DCPA acid metabolites (from 2.4% to 3.0%) and nitrate (from 57% to 64%) as a result of an analysis that involved estimation of the frequency of occurrence at all concentrations, *including those below the MRL*. A similar increase was noted for nitrate in CWS wells (52% to 56%).

- Although the Survey did not identify any CWS wells with pesticides at concentrations exceeding health based limits, estimates were developed, using the same procedures as were followed to generate similar estimates for the NPS Phase I Report. Using the upper bound of the 95% confidence interval, these estimates indicate that a maximum of 7.3 percent of CWS wells (corresponding to about 700 wells) containing pesticides exceed the maximum contaminant level (MCL) or Lifetime Health Advisory Level (HAL) for those chemicals for which an MCL or HAL has been established. (The mean proportion was estimated to be zero.) Using the upper bound of the 95% confidence interval, a maximum of 28.3 percent of rural domestic wells (approximately 125,000 wells) containing pesticides exceed the maximum contaminant level (MCL) or Lifetime Health Advisory Level (HAL) for those chemicals for when an MCL or HAL has been established. (The lower bound of the 95% confidence interval was estimated to be 3.4%, corresponding to approximately 15,000 wells, and the mean proportion was estimated to be 13.7%, corresponding to approximately 60,900 wells.)

Chapter Five: Conclusions and Recommendations

EPA's understanding of pesticides and nitrate in drinking water wells has changed as a result of the National Pesticide Survey. The Survey provided some support for many existing theories concerning well-water contamination, and a broader national picture of the problem emerges from the analyses conducted in Phase II.

Many of the statistical tests and analyses conducted for Phase II did not provide significant correlations among many of the factors that were expected to be correlated. In addition, there was some inconsistency in the significant correlations found for community water system wells and rural domestic wells. While there are plausible explanations for the inconsistencies, the results must be interpreted with caution as either a confirmation or a refutation of any model of the physical mechanisms or causation without further investigation, hypothesis testing, or model development. Chapters 2 and 3 provide extensive, detailed discussions of the limits and constraints in the NPS database. These conclusions reflect the careful deliberations and evaluations of the limitations of the Survey data. It is, however, useful to summarize why the Survey was unable to provide definitive relationships between pesticide use and occurrence.

As noted throughout the Phase II report, EPA's ability to investigate thoroughly the relationship of specific pesticide use and occurrence in drinking water wells was severely limited by the small number of detections (i.e., sample size) for most of the pesticides tested in the Survey. The limited sample size prevents an extensive analysis of the association of pesticide occurrence with expected contributing factors and limits the "power" of the Survey to detect the associations or correlations that may exist. In addition, using survey methods and secondary data to measure possible factors related to pesticide occurrence is a less precise method of assessing the potential influence of many of the factors that determine pesticide contamination of drinking water wells. The EPA recognized, early in the design of the Survey, the inherent problem of using respondent recall or expert opinions to develop measures of ground water characteristics and agronomic activity. This was the only cost-effective method of measurement and data collection for a national survey. Such data do, however, include measurement error that cannot be corrected and this further constrains the Survey's ability to uncover correlations that may be present.

Before establishing new policies to protect drinking water wells, readers should review these results in the context of data from other sources. These comparisons may offer important perspectives that the NPS does not fully explore. For example, the analyses were designed to identify factors that could be potentially useful topics for additional detailed research. The conclusions are based on a one-time "snapshot" of the nation's community water system and rural domestic drinking water wells. The analyses cannot definitively address factors affecting the presence of chemicals in drinking water wells that may change over time. Furthermore, the Survey's statistical design was chosen to provide national estimates of wells containing pesticides or nitrate. The results cannot address regional trends. The results of the statistical analyses carried out in Phase II may provide evidence of association between two variables, but such associations do not necessarily imply causation. The statistical analyses were guided by hypotheses that expressed plausible causal mechanisms. The Phase II results should not be interpreted to imply unambiguous attribution of causation. As an observational survey, the NPS cannot control all of the major factors that could influence the occurrence of pesticides and nitrate in drinking water wells. Finally, the choice of wells to be sampled and the number of water samples obtained by the Survey were determined primarily to estimate the number of wells contaminated by pesticides or nitrate (reported in Phase I). This choice was not ideally suited to carry out all the statistical analyses performed in Phase II. Thus, the conclusions reported in this chapter apply to the findings of EPA's National Survey of Pesticides in Drinking Water Wells. They should prove useful, in combination with the results of other studies, to inform the development of improved policies for drinking water well protection.

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5.1 Conclusions

The NPS results show associations between many different factors and the contamination of drinking water wells. The conclusions in this chapter are based on the evaluation of data quality, strength and consistency of statistical associations, and other factors discussed in Chapter 4. Although the Survey did not identify associations between reported uses of pesticides within 300 feet, 500 feet, or one-half mile of the sampled wells and detections in those wells, the Survey did identify associations between detections in both public and private drinking water wells and measures of agronomic activity (such as crop value and livestock production) that may be indirect indicators of agricultural use of pesticides and fertilizers. Similar analyses also identified relationships between non-agricultural use of DCPA and detections of its acid metabolites.

Nitrate's frequent presence in drinking water wells, already noted by a number of State and local surveys, is shown by the NPS to be a national situation. Furthermore, Phase II results show that nitrate's presence is associated with sales of fertilizers and with other sources of nitrate, particularly livestock production within the county.

Several other factors whose relationship to occurrences of pesticides in wells was already suspected also were identified in the Phase II analysis. Pesticide persistence, one of the criteria for determining whether particular pesticides were included as analytes in the NPS, was confirmed to be related to detections. Evidence suggests that more persistent pesticides occur in wells more frequently than less persistent pesticides. Shallower wells and, to a lesser extent, older wells were both shown to be associated with increased likelihood of detections of both pesticides and nitrate.

Other expected associations did not materialize in the NPS results. County-level measures of ground-water vulnerability did not correlate with detections in individual wells and pesticide mobility was not found to be associated with a greater incidence of detections.

When the significant single variables are grouped by the five broad categories of factors considered to be related to the presence of pesticides and nitrate in well water -- ground-water sensitivity, pesticide and nitrate use, transport mechanisms, chemical characteristics of pesticides, and the physical condition of wells -- a number of conclusions can be drawn. Each is highlighted in the following section along with a discussion of its significance.

(1) The Survey did not identify a useful measure of ground-water sensitivity from its county-level and sub-county level assessments for predicting the location of individual wells containing pesticides or nitrate.

The Agricultural DRASTIC system, used to generate measures of ground-water vulnerability (the term by which sensitivity was known at the beginning of the Survey) for purposes of stratification, did not function effectively when measured at the county level to locate drinking water wells containing pesticides or nitrate. DRASTIC is designed to assess the ground-water pollution potential of hydrogeological zones. A higher overall score, and consequently higher subscores, is expected to identify areas of higher potential ground-water vulnerability. Higher DRASTIC scores were not consistently associated with more frequent detections (the expected direction of association) or with less frequent detections. For example, at the county level, the average DRASTIC score and the subscores for net recharge and aquifer media were found to be related to detections, but in a manner contrary to that expected. These county-level DRASTIC results indicated associations between detections and lower overall scores or subscores. When a particular DRASTIC factor was associated with detections in CWS wells, the same factor was only infrequently associated with detections in rural domestic wells. For example, county-level results for topography and depth to water table indicated that a larger number of detections could be expected in areas of relatively low slope and shallow water table, but these results were not corroborated by appearing for both CWS and rural domestic wells.

Sub-county DRASTIC results showed similar inconclusive tendencies. The score for impact of the vadose zone indicated that more pesticide detections were associated with vadose zones in which relatively less attenuation occurred before chemicals reached ground water. Scores for aquifer media and the total DRASTIC score at the sub-county level were associated with nitrate concentrations.

Overall DRASTIC scores and subscores did not provide clear and unambiguous indicators for locating contaminated wells. A number of factors may have affected the ability of DRASTIC to identify vulnerable drinking water wells. The degree of misclassification, although considered acceptable for stratification, was recognized as an obstacle to analysis. The scale of application of DRASTIC may have obscured intra-county variability. Some DRASTIC factors partially overlapped and all factors affecting vulnerability are not included.

(2) The Survey's measures of pesticide use based on questionnaire data were not good indicators for locating drinking water wells containing pesticides.

The NPS was designed in part to test the proposition that pesticide use is related to pesticide detections in well water. Three direct sources of data were used. First, a proprietary source of pesticide marketing data was used to develop one of the two stratification variables. Second, the NPS devoted a great deal of attention in its data collection from well owners or operators to inquiries about the agricultural and non-agricultural use of pesticides on or near the property surrounding the sampled well. The areas of interest were defined as the property on which the well was situated or areas within 300 feet, 500 feet, or one-half mile of the well, depending on the particular question and respondent. Inquiries were made about farm and non-farm use, storage, and disposal of pesticides. Inquiries were also made about spills of pesticides and other mishaps or misuses. Although individual questionnaires were reviewed for internal consistency, questionnaire data were not validated from other sources. Finally, the Survey collected data on pesticide use from county agricultural extension agents, who were expected to be particularly knowledgeable about use in their areas.

The pesticide use estimates developed from marketing data that were used for stratification showed no correlation with a higher likelihood of locating wells containing pesticides. Detections in CWS wells occurred at almost the same frequency, irrespective of whether the well was located in the high, moderate, low, or uncommon pesticide use strata. The highest proportion of detections in rural domestic wells occurred in the low and moderate use strata.

Neither questionnaire data on the agricultural use of pesticides from well owners or operators nor questionnaire data from county agricultural extension agents was found to be associated with pesticide detections. Pesticides were detected where they were not reported as used, and reported as used where they were not detected. Four explanations, singly or in combination are possible: (1) that the three or five year period about which inquiries were made was not long enough to include the time when the pesticides were used or could migrate to nearby drinking water wells; (2) that respondents mistakenly or willfully underreported pesticide use and other activities or events, such as spills, that might have led to the presence of pesticides; (3) that the geographic area about which information was sought did not include the recharge areas of a significant number of wells; and (4) that pesticides were not detected in areas where they were reported as used because of detection limits, diffusion, dilution, sorption, degradation or other causes.

A "cropped and vulnerable" stratum, consisting of a combined score for ground-water vulnerability and cropping intensity, did not distinguish rural domestic wells in which pesticide detections were more frequent from other rural domestic wells. Although a slightly higher frequency of occurrence for pesticides was associated with rural domestic wells in the "cropped and vulnerable" stratum, the result was not statistically significant.

(3) Measures of pesticide use and of agronomic activity, such as data on crop values and livestock values collected from other sources and analyzed by the Survey, did show associations with pesticide detections in drinking water wells.

The NPS obtained data from several external sources for use in the analysis. The sources and principal results include the following:

(a) A database compiled for EPA by Resources for the Future, Inc., consisting of estimates of pesticide use by crop for selected herbicides and insecticides primarily used on farm crops; use estimates for 10 selected pesticides used by urban applicators; and use estimates for 10 selected pesticides used on golf courses. County-level estimates were calculated from regional totals for pesticides applied to specific crops, using estimates of the state's or region's total crop acreage. Analysis of the relationship between pesticide use, measured through the RFF database, and pesticide detections could be carried out for only one pesticide. The analysis showed an association between the amount of urban and golf course use of DCPA and greater likelihood of detection of DCPA acid metabolites in both CWS and rural domestic wells. No conclusive evidence was found that occurrences of DCPA acid metabolites in well water are associated with the rate of use of DCPA in agriculture as measured by the RFF data.

(b) A database consisting of county-level measures of agronomic activity compiled by the National Fertilizer and Environmental Research Center (NFERC) at the Tennessee Valley Authority from the 1987 Census of Agriculture, including general crop acreage, value of crop sales and value of livestock sales, specific crop acreage and production, and animal counts. Analysis of the relationship between these measures of agronomic activity and pesticide detections indicated a positive correlation between one of the five measures tested, market value of crops, and pesticide occurrence in rural domestic wells. No correlation was noted for market value of crops and CWS wells. Two other measures of agronomic activity that vary inversely with market value of crops, acres of pasture and rangeland fertilized and numbers of beefcows, showed a negative correlation with pesticide detections. The data show that acres in cropping decrease as pasture and rangeland and the number of cattle per county increase. If the market value of crops and acres of fertilized rangeland complement each other as indicators of pesticide use, then overall pesticide use decreases as cropping decreases. The results support the prior hypotheses.

(4) Measures of agronomic activity, such as data on fertilizer sales, crop values, fertilized acres, and market value of livestock, were found to be associated with concentrations of nitrate in drinking water wells, and also found (although less frequently) to be associated with nitrate detections.

(a) A database of state-level nitrogen fertilizer sales data compiled by NFERC. State-level estimates of fertilizer sales, prepared at West Virginia University using the NFERC data, were allocated to counties using factors developed from the 1987 Census of Agriculture. Significant correlations were found between sales of nitrogen fertilizer and nitrate *concentrations* in both CWS wells and rural domestic wells. Analysis of the relationship between nitrogen fertilizer sales, measured through the NFERC database, and *detections* of nitrate did not indicate an association between these variables. The reasons for this apparent inconsistency cannot be determined using NPS data.

(b) Using the same NFERC database of county-level agronomic activity described in (3)(b), measures of agronomic activity were tested for associations with nitrate detections and with nitrate concentrations. Crop value, acreage of cropland fertilized, and market value of livestock were all shown to be associated with nitrate concentrations above 0.15 mg/L in both CWS wells and rural domestic wells. A correlation between market value of livestock and nitrate detections was also observed.

The results described in conclusions (3) and (4) for the external databases are subject to several limitations. Some of the data reflect regional, state, or county-level measures of use of pesticides and sales of nitrogen fertilizers. Assumptions used in the process of extrapolating from regional or state level data to county-level data and then to well-level data could affect the results associated with well-specific detections and concentrations. Measures of sales indirectly reflect use, and the sales data may not accurately identify counties in which use actually occurs. In some cases, chemicals purchased in one location may not be used, or may be used in another location. Finally, comparisons of different databases indicate some discrepancies or inconsistencies in their estimates of pesticide use.

Despite these limitations, the results contain some suggestions that agricultural activity and livestock operations are associated with greater numbers of pesticide and nitrate detections. Market value of crops was associated with detections of pesticides in rural domestic wells. Sales of nitrogen fertilizers, crop value, acreage of cropland fertilized, and market value of livestock were associated with nitrate concentrations in both CWS wells and rural domestic wells.

Multivariate analyses, which tended to control for some of the confounding factors listed above, further support the findings concerning nitrate and pesticide use. The results of the multivariate analyses show that nitrate concentrations are affected by fertilizer use and agronomic activity. Two surrogate measures of agronomic activity that strongly predicted pesticide and nitrate detections were the market value of crops and acres of fertilized rangeland.

(5) Analysis of variables relating to transport of chemicals to ground water, including several precipitation measures, indicated that increased precipitation was inversely related to detections and concentrations of nitrate.

Data obtained from the National Oceanic and Atmospheric Administration concerning precipitation measured by weather stations in the counties in which detections occurred were analyzed for associations between rainfall variables and detections. Higher amounts of rainfall were found to be inversely correlated with nitrate detections. Several measures of precipitation for periods ranging from the month prior to sampling to five years prior to sampling all indicated that fewer nitrate detections and lower nitrate concentrations in CWS wells were associated with increased rainfall. Some evidence was obtained that intense precipitation over an extended period was associated with a reduced likelihood of pesticide detections in CWS wells. The probability of detecting pesticides or nitrate in rural domestic wells was generally not shown to be related to precipitation, although there is some evidence of an inverse relationship between nitrate detections and intense precipitation during the previous five years. The rainfall variable was measured in those counties nationwide where sampling occurred and provides a good estimate of average rainfall for the period being evaluated. The result suggests that after rainfall, pesticides and nitrate may run off before entering ground water or their concentrations may be reduced to the point where detections are less likely.

Some DRASTIC subscores related to water transport also were associated with detections, consistent both with the precipitation findings and with the design of DRASTIC. These results were not recurring in both the CWS and rural domestic well surveys. The subscores that showed an association were depth to water table and hydraulic conductivity. Parallel results were obtained for well-level variables from NPS questionnaire data. Shallow well depth was found to be associated with detections, while detections were less likely in wells that tapped confined aquifers.

The Survey investigated the presence and severity of drought, as measured by the Palmer Drought Index, in counties where sampling occurred. Analysis of these data showed that there was no discernable effect of drought on the Survey results. Sampling occurred in areas with conditions ranging from "extreme drought" to "extremely moist," as measured by Palmer Drought Index. No statistically significant different frequencies of occurrence of detections were shown among the categories. Some evidence, paralleling the results for precipitation, was obtained that nitrate detections in CWS wells were associated with moist conditions.

Finally, analysis of Survey questionnaire data on the presence of surface water near wells indicated that nitrate was less likely to be detected in either CWS wells or rural domestic wells located with such water bodies nearby. Presence of a body of water within 300 feet of the well also was negatively associated with pesticide detections in CWS wells. Rural domestic wells located within 500 feet of other operating wells and CWS wells located within one-half mile of flood irrigation were both more frequently associated with detections. The use of ground water for irrigation within one-half mile was associated with a lesser likelihood of detections. These results do not provide a consistent pattern of associations between detections and the nearby presence of surface water.

(6) The Survey identified well depth and to a lesser extent well age as factors related to detections of contamination.

Based on the results from Survey questionnaires, an association was found between detections and shallower wells, although NPS interviewers reported that well owners frequently lacked precise knowledge of the depth of their wells. A relationship between detections and wells drawing water from unconfined aquifers (consistent with the well depth results) was identified for nitrate detections in CWS wells. Weaker evidence also was obtained for association between detections and older wells.

(7) Phase II results suggest that several factors contributed to a smaller number of pesticide and pesticide degradate products being detected than would otherwise have occurred. The number of detections reduced the Survey's power and ability to identify possible relationships between well contamination and other factors.

The effective number of pesticide detections considered in the analysis was 44 in CWS wells and 17 in rural domestic wells. The effective number of nitrate detections considered in the analysis was 220 in CWS wells and 232 in rural domestic wells. The substantially greater number of times that nitrate was detected by the Survey supplied additional data points for nitrate occurrence that increased the ability to detect associations that may have been present. Accordingly, the Phase II analyses identified a greater number of associations involving nitrate detections or concentrations than involving any combination of pesticide occurrence data.

The number of pesticide detections available for inclusion in the Phase II analysis was affected by several factors. First, the Survey's statistical design was chosen to provide national estimates of wells containing pesticides or nitrate. The choice of wells to be sampled and the number of water samples obtained were not designed specifically to supply sufficient data to ensure that all the possible Phase II statistical analyses could be performed successfully. A substantially larger number of samples would have made it likely that additional analyses of pesticide occurrences would have been possible. Second, the stratified design did not, in fact, identify areas in which a higher proportion of wells containing pesticides were located. Third, the specification of minimum reporting limits designed to strictly control false positives meant that concentrations below the MRL were reported as nondetections. Concentration distributions were determined for DCPA acid metabolites and nitrate through extrapolation below the MRL and above the highest detected occurrence. The estimated occurrence frequency rose above that estimated using the MRLs. DCPA increased from 2.4% to 3.0% and nitrate from 57% to 64% in rural domestic wells. Additional analyses involving other analytes would have been possible at higher frequencies of occurrence if more samples had been gathered and/or if MRLs had been lower.

(8) Multivariate analysis produced models that suggest factors that may prove to be useful screening tools to identify drinking water wells likely to contain pesticides or nitrate.

Multivariate analysis was used in an attempt to identify a set of variables that best predicts the occurrence of pesticides and nitrate in drinking water wells. The Phase II analysis carried out multivariate regression analyses to determine if combinations of variables would be particularly strong predictors of pesticide and nitrate contamination of drinking water wells. Because of the relatively small number of pesticide detections and substantial commonality among variables, however, the predictive value of many of the factors considered in the analysis was difficult to evaluate. Very few variables appeared in more than one model. The best models were identified on the basis of how well they fit the data. The appearance of different variables in equally successful models does not necessarily reflect physical or theoretical interchangeability of the variables.

For pesticide detections, two variables -- fertilized pasture and rangeland and well depth -- provided the best model for detections of a pesticide in CWS wells. The presence of other operating wells near the sampled wells can be used in place of the well depth variable without substantially reducing model performance. An indirect measure of agricultural activity -- market value of crops in thousands of dollars -- by itself was the best model for pesticide detections in rural domestic wells. A variable measuring the number of beef cattle per acre could also be included. The small number of variables included the regression models largely reflects the effective sample size and number of detections for rural domestic wells, and should not be interpreted as showing that the factors under investigation are not related to pesticide occurrence in rural drinking water wells.

This Phase II multivariate analysis results parallel in part the logistic regression model identified by the NAWWS survey, which also contained a use variable. The NAWWS model, however, also reported a vulnerability variable. The variable identified by NAWWS, aquifer water level, bears some resemblance to factors identified in the NPS analysis, since it reflects the effects of precipitation and recharge.

For nitrate detections, a three-variable model, composed of fertilized pasture and rangeland, average monthly precipitation, and well-water pH, provided the strongest results for nitrate detections in CWS wells. Farming on the property where the well is located also can be included in the model. A four-variable model, composed of well age, maximum monthly precipitation in the five years prior to sampling, well water pH, and the presence of an unlined drainage ditch within less than one-half mile, created the best model for nitrate detections in rural domestic wells. A variable for fertilized pasture and rangeland could also be included.

For nitrate concentrations in CWS wells, five variables -- maximum monthly precipitation in the past five years, well water electrical conductivity, total nitrogen sales by county for counties containing wells in which nitrate was detected, well depth, and a categorical variable that reflects the Palmer Drought Index score for the year prior to sampling -- create the best model. Crop value can be used in place of total nitrogen sales without substantially reducing model performance. For nitrate concentrations in rural domestic wells, four variables are included in the best model -- well depth, market value of crops, presence of an unlined body of water within one-half mile, and the Agricultural DRASTIC subscore for topography measured at the sub-county level. Total nitrogen sales can be used in place of crop value. A variable for the presence of a body of water within 300 feet of the well could also be included.

(9) Estimates of the concentration distributions for DCPA acid metabolites and nitrate were prepared. The estimates indicate that over 10 million persons are exposed to DCPA acid metabolites in drinking water wells. Very few are expected to be exposed to levels above the health advisory or MCL. Approximately 1.5 million persons could be exposed to nitrate, above the maximum contaminant level of 10 mg/L.

Estimates of the concentration distributions for nitrate and DCPA acid metabolites were prepared for both CWS and rural domestic wells. These estimates are calculated from detections above the MRL and on maximum likelihood estimates of concentrations below the MRL. They indicate that the frequency of occurrence of those pesticides is somewhat greater than indicated by the estimates reported in the NPS Phase I Report, which were calculated from concentrations that exceeded minimum reporting levels. Approximately 64% of rural domestic wells (6,720,000 wells) and 56% of CWS wells (53,000 wells) are estimated to contain nitrate. Approximately 3.0% of rural domestic wells (315,000 wells) are estimated to contain DCPA acid metabolites, and about 100% of CWS wells are estimated to contain extremely low levels of DCPA acid metabolites.

EPA estimates that about 10.4 percent of CWS wells and 4.2 percent of rural domestic wells contain detectable levels of one or more pesticides. The Phase II study estimated the chance that a well that contains one or more pesticides also exceeds a maximum contaminant level or health advisory. EPA estimates that no more than 7.3 percent of the 10.4 percent of CWS wells that contain one or more pesticides could exceed an MCL or health advisory. Similarly, no more than 28.3 percent of the 4.2 percent of rural domestic wells that contain detectable levels of one or more pesticides are also expected to exceed a health based limit. In summary, about 1 percent of all drinking water wells in the U.S. are estimated to exceed a health based limit. EPA concluded that the overall chance of a given well exceeding a level of concern for a pesticide is low. If a well contains a detectable amount of one or more pesticides, it has a slightly higher risk of also exceeding a health based limit. EPA recommends that well owners that know or suspect that their well is affected by pesticides have the water tested to ensure that any pesticides are present at levels below the MCLs or health advisories.

Quantitative exposure and risk estimates prepared in Phase II for the populations served by wells containing DCPA acid metabolites indicate that, as indicated in Phase I, the current potential health effects are low. Approximately 1.2 million people are estimated to drink water from rural domestic wells and 9.4 million drink water from CWS wells that contain DCPA acid metabolites, but none are exposed at concentrations above the Lifetime Health Advisory Level of 4,000 $\mu g/L$.

Approximately 19 million people are estimated to be exposed to nitrate in rural drinking water wells, with about 1.5 million exposed to levels of nitrate over the Maximum Contaminant Level of 10 mg/L (ppm), and approximately 22,500 infants under 1 year old exposed to a concentration of greater than 10 mg/L. Persons with high levels of nitrate in their private wells should consult their pediatricians and may wish to obtain water from alternate sources that have less than 10 mg/L of nitrate to help protect infants from the risk of methemoglobinemia (blue-baby syndrome). Physicians are usually well informed about the risks to infants of high levels of nitrate in drinking water and are able to provide medical treatment. Approximately 85 million people are estimated to drink water from CWS wells that contain nitrate, with about 3 million exposed to levels of nitrate over 10 mg/L (ppm), and approximately 43,500 infants under 1 year old exposed to a concentration of greater than 10 mg/L. Public water supplies that violate the Maximum Contaminant Level of 10 mg/L for nitrate are required to notify their customers about the violation, and the adverse health effects caused by nitrate. (40 CFR 141.32) Local and state health authorities are the best source for information concerning alternate sources of drinking water for infants. Systems that apply for variances or exemptions while in violation of the standard may be required by the state to provide bottled water or point-of-use or point-of-entry devices to avoid unreasonable risks to health. (40 CFR 141.62(f))

5.2 Recommendations

This section presents several recommendations for planning and design of future surveys and other studies. They offer ideas on how to expand the results of this Survey and of future similar studies. The recommendations offer ideas on ways to study the presence of pesticides and nitrate in drinking water, new questions, and subjects that need to be further investigated.

Three aspects of survey design had particularly strong effects on the quality of results achieved. They are:

- Stratification of the country by anticipated probability of contamination;
- Methods of data collection; and
- The number of wells to be sampled.

The Survey's results suggest ways in which each of them could be improved.

Stratification. Oversampling of strata should be undertaken only if the criteria used can be measured with sufficient accuracy to improve the survey estimates and precision. This requires an alternative to the county-level DRASTIC scores as implemented in the NPS. The NPS spent considerable energy and resources on attempting to identify those areas of the country most likely to be contaminated by pesticides. Survey designers expected that by stratifying and oversampling such areas the Survey would be more likely to obtain a representative picture of the presence of pesticides and nitrate in drinking wells across the country. All eligible wells for both the rural domestic well and community water system surveys were stratified according to the county in which they were located. A twelve category stratification was used, based on surrogates for pesticide usage and ground-water vulnerability. The former was based upon pesticide sales and agricultural information that was only available at the county level. The latter was based on county-level DRASTIC measures. For the rural domestic well survey, wells were further stratified at the second stage (sub-county), based on whether they were located in cropped and vulnerable parts of the county.

In order for improved precision to result from oversampling of strata, the stratification variables should have an effect on what is being measured and they must be measured with reasonable accuracy. Furthermore, oversampling, such as the oversampling in cropped and vulnerable areas, is advantageous when a very high percentage of contaminated wells are known to be in the oversampled strata. Because stratification did not effectively identify high risk areas, oversampling did not increase the precision of the Survey's estimates. The Phase II results indicate that neither the overall DRASTIC score nor the individual subscores at the county level functioned effectively, with both the design of the DRASTIC model and the implementation of the scoring responsible in part for the ineffectiveness of county-level stratification. With respect to the sub-county stratification based on a definition of "cropped and vulnerable," little evidence was obtained to indicate that the sub-county stratification performed better than the county-level stratification. The ineffectiveness of second-stage stratification in turn limited the effectiveness of oversampling.

Stratify by pesticide use only if a good *local* measure of such use is available. The second weakness in the stratification was that the pesticide use data used for stratification only dealt with agricultural pesticides. The pesticide most frequently identified in wells by the NPS, DCPA acid metabolites, is frequently used in non-agricultural settings. Even for agricultural pesticides, the county level data and reports by well owners do not appear to have identified wells more likely to contain pesticides.

Ensure that the data used for stratification include accurate data about wells. A third potential weakness in the stratification used for the NPS that may have diminished its effectiveness was that the frame of community water systems, the Federal Reporting Data Systems (FRDS), did not identify the location of individual wells. It also did not indicate the number of wells used by a CWS. If FRDS is to be used as a frame for future surveys it should first be evaluated for its coverage and accuracy of reported data on well location and system size. When determining the location of the well with respect to the oversampled counties, it was assumed that all wells in a system were located in the same county as the system's mailing address. While this assumption is likely to be true in most cases, it is known to be false in at least a few cases.

In summary, these judgments concerning the effectiveness of stratification variables imply that future surveys should not heavily oversample, since it is not known in advance which areas are most likely to be contaminated. For the same reason all areas of the country should continue to be given a chance of inclusion in pesticide studies. Even if it is accurately known that all the pesticides being studied are not sold or used in a particular part of the country, such areas must be included in order to obtain national estimates. Thus a typical two-stage design might stratify the country geographically at the first stage to ensure representativeness but not do any oversampling. Counties might still be the unit selected at the first stage to reduce travel costs. At the second stage it might be desirable to oversample areas thought most likely to be contaminated. Such oversampling should be light unless there is great confidence in the predictive power of the stratification variables.

Methods of Collecting Data. The NPS provides good information on the quality of data that can be collected from both laboratory analyses and questionnaires and useful guidance on how such methods might be improved.

The new cost-effective multi-residue methods that were developed for use in the NPS should continue to be of great use for other environmental studies. These methods enable analysts to search for large numbers of analytes simultaneously while limiting the costs of the analysis. One drawback to the use of multi-residue methods, however, is that they tend to be less precise for individual analytes and therefore to have higher detection limits than methods concentrating on a single analyte. Whatever methods used, all concentration data obtained should be reported.

In addition to reporting data from chemical analyses for which both qualitative and quantitative accuracy is assured, also report additional results (with less than the specified levels of precision) of chemical analysis while maintaining a high degree of quality assurance through confirmation of the presence and identity of the analytes. The identification of all pesticide and pesticide degradation products detected in the NPS was both qualitatively and quantitatively confirmed. Confirmations were conducted by reanalyses of all sample extracts using a second capillary gas chromatographic (GC) or high performance liquid chromatographic (HPLC) column. These analyses provided both a preliminary qualitative confirmation for all GC determinations and the final confirmation for HPLC analyses. The analytes detected using a GC-based method were also qualitatively confirmed using gas chromatography/mass spectrometry (GC/MS).

In the future, in addition to reporting data that have satisfied both qualitative confirmation and quantitative measurement (equivalent to data exceeding specified MRLs), a second tier of data should be reported that have been qualitatively confirmed but which have not been quantitatively measured at the specified levels of precision. Such results should be reported with sufficient information to judge the reliability of the reported concentrations, assuming that all gas chromatographic identifications have been subject to at least one confirmation step. This two-tiered system will maintain data quality requirements for reporting data associated with specific sampling sites (such as the notice given to well owners and operators of confirmed detections above the MRL) while increasing the number of data points available for statistical analysis using data in which only the identity of the analyte has been assured. In particular, statistical analyses of categorical variables, which is less sensitive to precise measurement of detections, would be enhanced. Broader reporting of data, along with evaluations of its precision and accuracy, would allow a wider variety of analyses of the type included in this Phase II report without endangering the accuracy of the national estimates that were included in the NPS Phase I report. Analysts would have to continue to be very careful of the sensitivity of their statistical findings to the quality of the laboratory data. This approach would be consistent with the suggested new American Chemical Society guidelines, which are currently under development, and advocate reporting of all analytic data, including data below the level at which quantitative results may be obtained with a specified degree of accuracy, if it is completely documented with respect to problems and limitations.[1]

Questionnaire data may be limited in quality for topics that are sensitive to respondents such as pesticide spills and disposal. The NPS results show that it is possible to collect useful information related to pesticide contamination of wells using questionnaires administered to homeowners, renters, well operators, and agricultural extension agents. Data collection by telephone also worked effectively. But respondents do not appear to have provided good data on several of the key factors associated with the presence of pesticides or nitrates in drinking water wells, including pesticide use, spills, and disposal.

There are at least four possible explanations of why NPS respondents did not report the use of pesticides near wells where those pesticides were detected: the pesticides had migrated through the ground water and had not been used near the well; the respondents could not (or did not wish to) recall using the pesticide; the respondent only remembered a generic type of pesticide (e.g., crab grass killer) for which it was impossible to determine the active ingredient; or the number of wells with pesticide detections was too small to find such a relationship. There is little that can be done to modify the first three causes of this limit of the utility of the questionnaire data. The last cause can be reduced by increasing the size of future surveys or by dropping or relaxing the use of MRLs.

It is important that future surveys ask about non-agricultural fertilizer use in addition to agricultural use. When the NPS was designed its emphasis was on detecting agricultural pesticides. The NPS asked about both agricultural and non-agricultural pesticide use but asked only about agricultural use of fertilizers. Some of the nitrate contaminating ground water may occur as a result of lawn applications.

Number of Drinking Water Wells to be Sampled. The NPS had two main goals: to estimate the number of drinking water wells in the United States contaminated by pesticides and to examine relationships between contamination and a variety of explanatory variables. The determination of the number of wells to be sampled was only based on achieving the first of these two goals. In fact, the national estimates reported in the Phase I report had a greater level of accuracy than was anticipated when the survey was designed because more wells contaminated by pesticides were found in the sample than had been anticipated in the design. Extensive statistical analysis of survey data in Phase II was limited by the number of detections that could be included in such analyses. In particular, a modest increase in the number of pesticide detections available for analysis might have substantially increased the number and explanatory power of the significant findings and conclusions.

When determining the sample size for the National Pesticide Survey EPA decided to design the study to meet certain accuracy requirements for the Phase I analysis, and to conduct whatever limited Phase II analyses would be possible. This is what has been done. If future studies wish to both produce national estimates and conduct in-depth relational analyses they may require significantly larger sample sizes than used for this survey.

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[1] Keith, L.H., Report Results Right!, Part 1, June 1991, CHEMTECH, pp. 352-356, and Report Results Right!, Part 2, August 1991, CHEMTECH, pp. 486-489.

Type of Study. The NPS obtained the first national estimates of the presence of pesticides and nitrate in drinking water wells. For that purpose, a national survey was indispensable. No other method will provide good national estimates for a variety of analytes. The amount of data sufficient to develop accurate national estimates, however, was not sufficient to perform statistical analyses in Phase II for all of the chemicals and all of the issues identified. Furthermore, the Phase II analyses could identify associations between variables, but they could not address questions of causation. Selective use of hot spot studies and case control studies is one method of achieving the different sample sizes required for different analytic purposes. Each of these types of studies can be appropriate for specific situations.

Hot spot studies can provide detailed information on causes and relationships between contamination by individual analytes and other variables. These studies are relatively inexpensive, can provide excellent insights, and can be useful in developing hypotheses. Since hot spots are by definition not representative of the nation such studies cannot be used to test hypotheses for application to the nation as a whole. They might be used, for example, to examine the unexpected findings on the incidence of DCPA acid metabolite contamination.

Case control studies with standardized methods can be used for comparing hot spot wells with other wells in similar conditions to test broad hypotheses. Two potential drawbacks to case control studies are the fact that hot spot wells may not be representative of all contaminated wells, and the set of comparisons that can be made are limited by the size and scope of the study.

Additional Research. The Survey analysis identified a number of topics that could be useful areas for future study:

- **Analysis of links between surface and ground-water contamination.** The Phase II analysis identified associations between rainfall, the presence of nearby water bodies, irrigation, and detections.

- **Analysis of recharge and ground-water flow.** The NPS did not collect data on the direction of ground-water flow or to calculate recharge for sampled wells. Additional evaluation of potential sources of contamination could be conducted with such data.

- **Studies of seasonal and temporal effects on contamination.** The NPS was not designed to examine temporal variations or seasonal effects on contamination. Continuing study of those questions is necessary to better understand how detections and concentrations vary over time.

- **Evaluation of site-specific data on soil characteristics.** The NPS did not collect data on soil profiles near sampled wells. Additional evaluation of pesticide persistence and mobility could be conducted with such data.

- **Investigation of the greater prevalence of contaminants in CWS wells compared to rural domestic wells.** The results supply some inconclusive evidence that CWS wells may be more vulnerable to contamination than rural domestic wells.Greater drawdown by large system wells, recharge areas for CWS wells, and non-agricultural use of pesticides could be investigated.

- **Development of statistical procedures for examining small samples of weighted survey data.** Currently existing statistical procedures for analyzing small sample sizes do not allow the inclusion of weights such as those designed for the NPS.

- **Analysis of non-agricultural uses of pesticides and their impacts on water quality.** NPS results involving DCPA acid metabolites obtained from data on non-farm use of pesticides suggest that non-agricultural sources are strongly associated with detections.

- **Analysis of pesticide degradates.** The frequency of detection of DCPA acid metabolites also confirms the importance of considering pesticide metabolites in the design of studies.

- **Development of improved data on pesticide use.** Survey experience shows that better data concerning pesticide use and application are required. Analysis of NPS pesticide use data has included data from several sources; data used to construct stratification variables, data from NPS questionnaires, RFF data, and manufacturer's data. The problems encountered with analysis of stratification variables and pesticide use data from questionnaires, and the differences between RFF and manufacturer's data suggested that an accurate picture of pesticide use nationally is not available. Reconciliation of these pesticide use data or provision of accurate data on a farm level basis would allow development of a more accurate and useful pesticide use database. Greater availability of accurate, locally precise pesticide use and distribution data in the public domain would help to ensure that assessments of the vulnerability of drinking water wells to contamination can be improved and made more reliable.

The NPS Phase II results show that pesticides could be present at low levels of concentration in a greater number of wells than originally estimated in Phase I. Several specific indicators are related to the contamination of wells across a broad spectrum of site-specific conditions. Due to lack of sufficient detections for statistical analysis, lack of findings of relationship between detections and possible factors indicating a likelihood of detection should not be interpreted as showing that there is no relationship between detections and these factors. There are, at present, no simple inexpensive methods to identify vulnerable wells likely to experience contamination. NPS data cannot develop models that apply to site-specific conditions or account for every conceivable factor that determines the fate and transport of chemicals in ground water. The Phase II results show that it is difficult to identify a simple set of factors that may always reduce the presence of pesticides in wells. The Phase II results show that many factors and practices contribute to the problem of pesticide and nitrate contamination. Protection of drinking water quality is best accomplished using a comprehensive integrated approach that emphasizes prevention of contamination to account for a wide variety of factors.

National Pesticide Survey

Appendix A: Results of Univariate Chi Square (X^2) Tests with Significance Level (P-Value) Between 0.05 And 0.1

Summary of Ground-Water Sensitivity Variables Associated with Detections in Drinking Water Wells (Significance Level > 0.05 ≤ 0.1)

Variable	Nitrate				Pesticides			
	Community Water System Wells		Rural Domestic Water Wells		Community Water System Wells		Rural Domestic Water Wells	
Level of Measurement Variable Name	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value
COUNTY								
Net recharge					+	0.092		
"Most likely" total score			-	0.053				
"Weighted average" total score			-	0.077				
Adjusted WGTSCORE			-	0.078				
Impact of vadose zone							-	0.068
Topography							+	0.074
Impact of vadose zone (nitrate > 3 mg/L)			-	0.100				
SUB-COUNTY								
Topography			-	0.058				
Depth to water table (log(concentration))			+	0.094				
Impact of vadose zone (log(concentration))			+	0.057				
Hydraulic conductivity (log(concentration))			+	0.070				
Soil media							+	0.093
Aquifer media							+	0.060
Topography (nitrate > 0.15 mg/L)			-	0.068				
Aquifer media (nitrate > 0.3 mg/L)			-	0.058				
Soil media (nitrate > 0.3 mg/L)			+	0.055				
Depth to water table (nitrate > 3 mg/L)			+	0.092				
DRASTIC (nitrate > 3 mg/L)			+	0.069				
Aquifer media (nitrate > 10 mg/L)			+	0.093				
Topography (nitrate > 10 mg/L)			+	0.083				
WELL								
Age (ln)					+	0.085		

Summary of Transport Variables Associated with Detections in Drinking Water Wells (Significance Level > 0.05 ≤ 0.1)

Variable	Nitrate				Pesticides			
	Community Water System Wells		Rural Domestic Water Wells		Community Water System Wells		Rural Domestic Water Wells	
Level of Measurement Variable Name	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value
COUNTY								
Temporal by month							N/A	0.080
Precipitation during last five years					-	0.053		
SUB-COUNTY			-	0.077				
Irrigation used within half mile of the well							+	0.057
Drainage ditch within 300 feet of the well					-	0.079		
Unlined drainage ditch within half mile of the well							-	0.063
WELL								
Drainage ditch within 300 feet of the well					+	0.076		
Cased to total depth	+	0.055			+	0.080		

Summary of Use Variables Associated with Detections in Drinking Water Wells (Significance Level > 0.05 ≤ 0.1)

Variable	Nitrate				Pesticides			
	Community Water System Wells		Rural Domestic Water Wells		Community Water System Wells		Rural Domestic Water Wells	
Level of Measurement Variable Name	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value	Direction of Effect	p–value
COUNTY								
Pesticide use	N/A	0.087						
Land in orchards							+	0.054
Vegetables harvested for sale							+	0.063
Animal husbandry					+	< 0.1		
Corn in acreage for grain	+	0.089						
Market value of crops including greenhouse and nursery	+	0.077						
SUB-COUNTY								
Septic field within half mile of the well	–	0.060			–	0.091		
Golf course within half mile of the well	–	0.059						
Municipal or industrial waste treatment facility within half mile of the well					+	0.080		
WELL								
Septic field on property where the well is located			–	0.080				
Animals raised for farm purposes							–	0.088

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